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Severe weather forecasting for Laughlin, AFB, TX

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THESIS

SEVERE WEATHER FORECASTING FOR LAUGHLIN AFB, TX

by

Eric J. Cercone

March 2007

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A sounding climatology of a variety of parameters commonly used to forecast deep, moist convection using upper-air observations is developed. The data set includes 0000 and 1200 UTC rawinsonde data (approximately 3629 soundings) from Laughlin AFB, TX from April–September 1995–2004. Cloud-to-ground lightning data, surface observations, and severe weather reports from the Storm Prediction Center (SPC) SeverePlot2 Program were used to categorize soundings as representative of conditions for no convection, light convection, convection within vicinity, moderate severe convection, or severe convection. Indices, including convective available potential energy (CAPE) and mean layer CAPE (MLCAPE), along with sounding parameters and combinations of such as 0-2 and 0-6 km bulk shear, 700-500 mb lapse rate, lifted condensation level (LCL) and mean layer LCL (MLLCL) heights, are examined in an attempt to distinguish between moderate and severe convection.

The results show that the 0-6 km bulk shear along with the MLCAPE and LCL height indicate some discrimination between the moderate and severe categories. The best discrimination comes from the significant severe parameter, calculated by taking the product of the 0-6 km bulk shear and MLCAPE, and the 0-6 km bulk shear versus MLCAPE, and the 700-500 mb lapse rate.

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SEVERE WEATHER FORECASTING FOR LAUGHLIN AFB, TX

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Submitted in partial fulfillment of the
requirements for the degree of

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I. INTRODUCTION

A. CHALLENGE OF SEVERE CONVECTIVE WEATHER FORECASTING AT LAUGHLIN AFB, TX

In April 2002, a severe hailstorm moved over Laughlin AFB, TX with little to no warning. Flying missions at and around the base had to be quickly diverted, and the base, along with unprotected aircraft, suffered heavy damage. Since the wing's main mission is specialized undergraduate pilot training, the experience level of weather within the undergraduate pilot community is fairly low. Hazardous weather poses significant safety and financial issues (Keaveney, 2005).

Laughlin is located at 29.27^{o}N 100.42^{o}W, six miles east of Del Rio, TX, near the Rio Grande River. The surrounding area is relatively flat about 1082 ft / 334 m above sea level. See Figure 1. About 40 miles southwest of Laughlin are the Burro Mountains of Mexico which range from about 4,500–9,000 ft. These mountains are a significant development region of thunderstorms impacting the base, especially in severe weather season (Apr–Sept). Lack of data makes forecasting difficult; but the threat these storms pose makes accurate forecasting paramount. (Laughlin Terminal Forecast Reference Notebook, TFRN, 1993)

Laughlin's mission is to conduct undergraduate pilot training for the 47th Flying Training Wing and the 85th and 87th Flying Training Squadrons. Weather affects not only the flying community but also a total of 13 other supported units. The effects of weather on the flying community range from a total loss of all sorties to restricted airspace patterns. The significant phenomena range from thunderstorms (TS) and/or lightning (LTG) within 3, 10, 15, 20, and 30 nms, winds > 30 > 35 > 50 > 70 kts (as low as 12 kts for parasailing near the hospital), hail > ¼” > ¾”, and tornadoes.

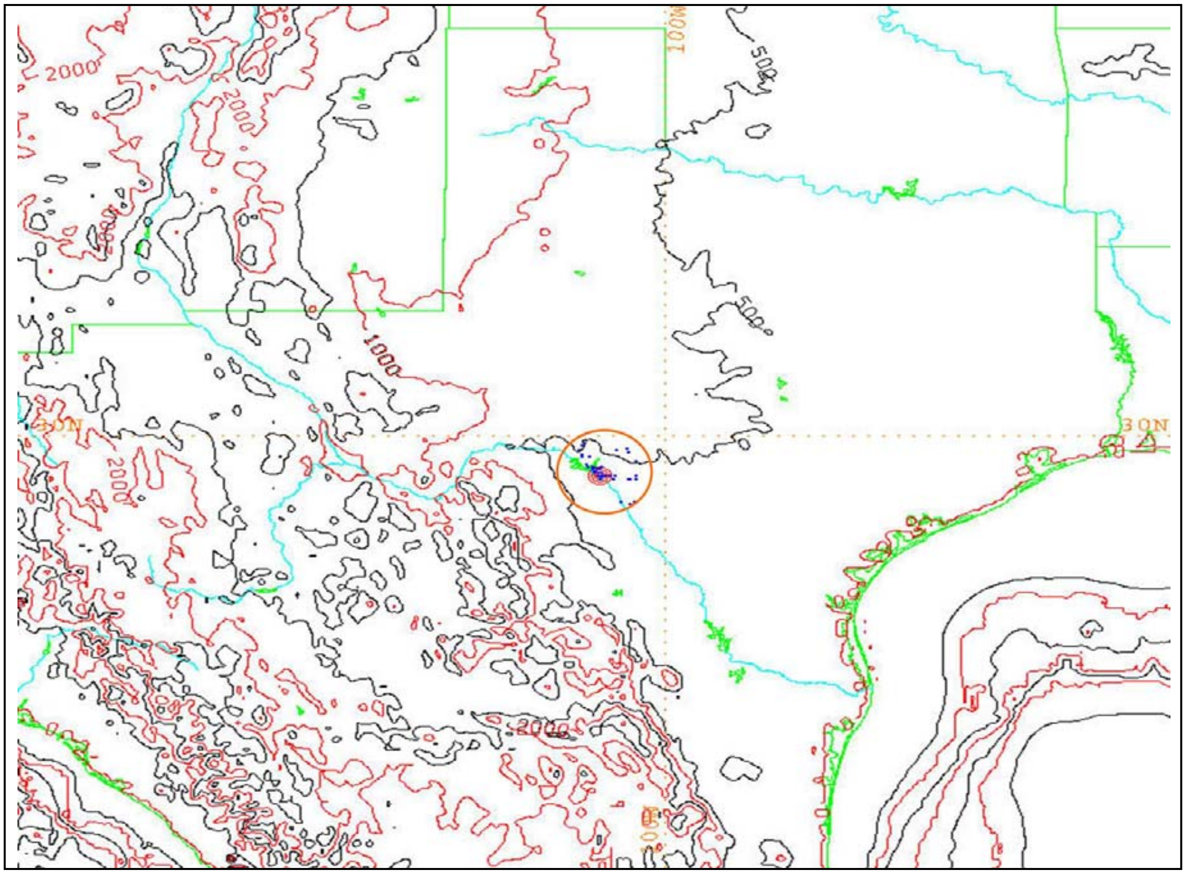

Figure 1. Location of Laughlin AFB, TX (red circles), the local topography (red and black elevation lines in meters), the 30 nm flying radius (orange circle), along with the location of all severe events that occurred during April-September 1995-2004. The green and blue lines depict borders between the USA and Mexico while the blue lines also represent rivers/waterways.

B. SCOPE OF THESIS

The scope of this thesis is to provide meteorologists at Laughlin AFB with improved information on predicting the occurrence of severe thunderstorms as requested in the Air Force Weather Agency 2005 Thesis Topic List (Keaveney 2005). Since this region is data sparse, there are numerous meteorological tools that could be studied, such as satellite data or numerical model forecasts. The most reliable data set for Laughlin is the twice a day soundings which are available back to 1973. The approach selected for this study is to use these upper-air observations in preparation of a sounding climatology for Laughlin AFB. This climatology will provide additional guidance from the detailed sounding data on what parameters are associated with severe convection for this specific region. A forecaster, then, can take those parameters and apply them to numerical modeling or satellite retrievals for data sparse regions, or possibly for a nowcast. Since numerical modeling and satellite data retrieval is continuously improving, it is important to focus and guide the interpretation of soundings for future use at Laughlin AFB.

The thesis begins with background information in convection forecasting in Chapter II. Chapter III presents the data and methodology used while Chapter IV presents the results. The thesis concludes with recommendations for future work in Chapter V.

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II. BACKGROUND

A. SEVERE CONVECTION

Severe convection produces a variety of hazardous weather events, such as large hail, damaging wind gusts, tornadoes, and heavy rainfall. This section provides background on deep, moist convection, static stability, and the elevated mixed layer.

1. Deep, Moist Convection (DMC) and its Hazards

Deep, moist convection is caused by the release of vertical instability in the atmosphere. In order for convection to reach into the troposphere, there must be strong updrafts (presence of lightning indicates stronger updrafts) that can overcome any low-level inversion created by a capping inversion or elevated mixed layer (EML). Intensity is one way to classify DMC. According to Stratton (2006) “convection that culminates in rain showers is assumed to be of weaker intensity, while DMC that culminates in thunderstorms is assumed to be of stronger intensity.” Deep moist convection occurs on many horizontal scales and is associated with a variety of synoptic circulation systems.

2. Static Stability

One particularly important condition is the troposphere's state of static stability. A weakly stable atmosphere with low level moisture and a triggering mechanism, along with cool dry air aloft, are the necessary factors in developing convective precipitation. Density and temperature are the two factors that are considered when determining static stability. “For example, an upwardly-displaced air parcel, if lighter (i.e., generally warmer) than its environment at its new level, is said to be "unstable" and will rise freely on its own, while if heavier (cooler) than its environment, it is said to be "stable" and will settle back towards its initial position” (Peppler, 1988).

A number of indices have been developed to assess the degree of static stability present in the atmosphere. Most have been defined in terms of the concepts of conditional, absolute, latent, and potential/convective instability and are based on the vertical displacement of a hypothetical air parcel, or an entire atmospheric layer of some prescribed isobaric thickness. Classic indices include the K Index, Lifted Index, Showalter Index, Total Totals Index, Severe Weather Threat (SWEAT) Index, and Convective Available Potential Energy (CAPE). (See Appendix D for definitions of indices).

3. Elevated Mixed Layer

Several studies have indicated that elevated mixed layers (EMLs) have been found to be an important factor in the development of springtime thunderstorms over the southern and central Plains states (Carlson and Ludlam 1968; Carlson et al., 1980; Carlson et al., 1983; Benjamin and Carlson 1986; Lanicci and Warner 1991a, b, c). Lanicci (1991a, b, c) notes that "these layers are created when boundary-layer air that forms over elevated terrain loses convective contact with the ground as it is advected off the elevated terrain and overruns a boundary layer forming over lower terrain."

Carlson et al. (1983) discussed a conceptual model, Figure 2, of how the capping inversion associated with the elevated mixed layer focuses the location and even enhances the intensity of severe local storms. The capping inversion prevents convection from developing in area of high CAPE, allowing the boundary layer to warm and moisten further and permit the buildup of additional potential instability. Doswell et al. (1985) discussed the importance of steep 700-500 hPa lapse rates for the creation of strong conditional instability. The location of steep lapse rates and low-level moisture was shown to be ideal for severe storm/tornado formation. Previous research done by Lanicci (1985) and Lanicci and Warner (1991a, b, c) showed that the elevated mixed and the capping inversion, which is normally located between 850 and 700hPa, are very important to convective development layer over the southern and central Great Plains. Steep 700-500 hPa lapse rates are typically associated with an elevated mixed layer. Therefore, the 700-500 mb lapse rate is useful in tracking elevated mixed layer air and capping inversions that have originated over the higher terrain of the western U.S. or northern Mexico (Craven and Brooks 2004).

The EML and/or capping inversion plays a large role in the Laughlin region and are associated with the dew point discontinuity front or dryline, Figure 2. The dryline is usually on the lee-side trough of a low pressure which extends southward across west Texas into northern Mexico. It has a mean position along the western edge of the Texas panhandle. This trough marks the westward extent of moist air flowing in from the Gulf and is characterized by a rather sharp dew point discontinuity and sometimes a wind shift. In the summer it marks the westward extension of the Bermuda high. The dryline usually remains quasi-stationary until late morning and then begins to move eastward. It is partly responsible for thunderstorm activity and is key feature to watch in the spring. (Laughlin TFRN 1993)

Figure 2. Schematic flow diagram, representing in three dimensions the airstreams M, CD and SP, is shown in perspective against topography of southern Great Plains of the United States and Mexico. Thin dotted lines denote surface terrain elevation contours and illustrate the gradient of surface elevation north and east of the high plateau of Mexico (shown in cut away section). The left edge of the moist airstream (M) is shown bounded by the dryline (dot-dashed line); the left edge of the Mexican airstream, labeled CD which is forming a lid over the moist air, is denoted by the scalloped border. Thunderstorms can also occur underneath the lid at the location of the asterisk where large-scale ascent coupled with surface heating may be removing the lid. The third airstream SP is the subsiding polar air which originates west of the trough. *From Carlson (1991)

B. CLIMATOLOGY OF SEVERE CONVECTION

Laughlin reports an average of 25 thunderstorms annually, while within a 120 mile radius of the base, thunderstorms occur about 100 days a year. Of the 25 annual storms each year, 19 are reported during the period April–September. Small hail, ¾”, is reported about twice a year at the base, while severe hail is reported about once every five years, with the largest recorded as 5 inches in diameter which fell on 16 March 1987. During the spring and summer months the lapse rate is weakly stable with insufficient moisture to support more than isolated activity, but thunderstorms are an almost daily occurrence in the extreme southeast and western portions of the area. (Laughlin TFRN 1993)

Thunderstorms usually occur most frequently in the spring and fall. During periods of low-level southeasterly flow (Maritime Tropical Air) from April through September, thunderstorm activity frequently develops 65–100 miles west-southwest of Laughlin on the eastern slopes of the Burro Mountains, where storm tops can exceed 50,000 feet. See Figures 3 and 4.

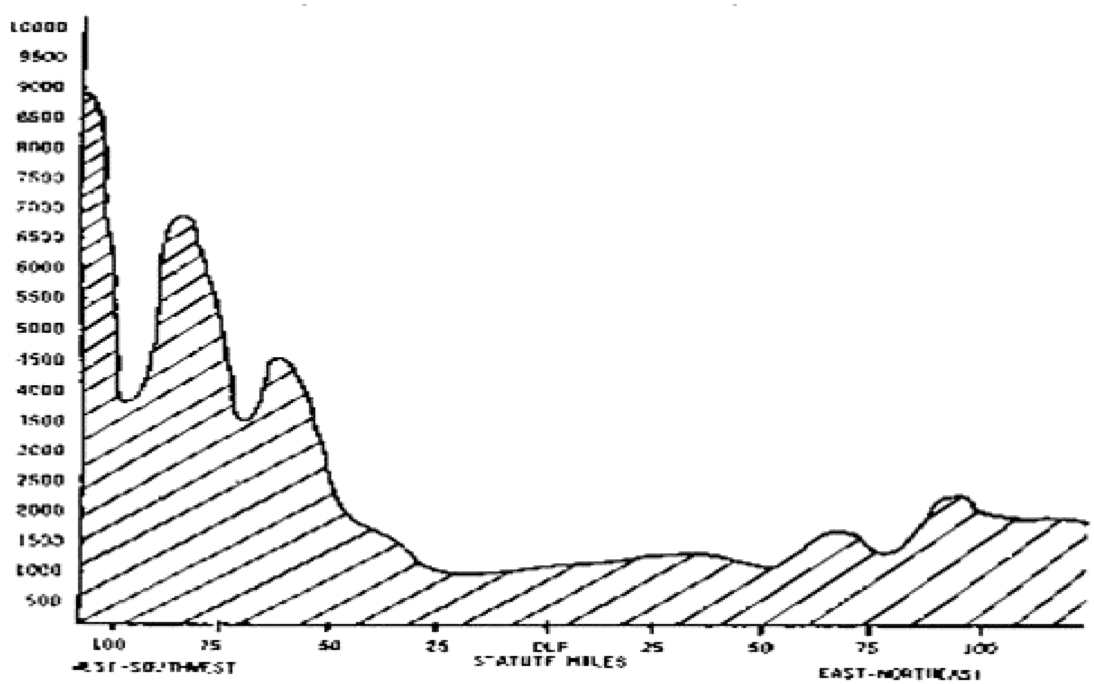

Figure 3. West-Southwest to East-Northeast terrain cross section height in feet (y-axis). *Courtesy of Laughlin TFRN (1993)

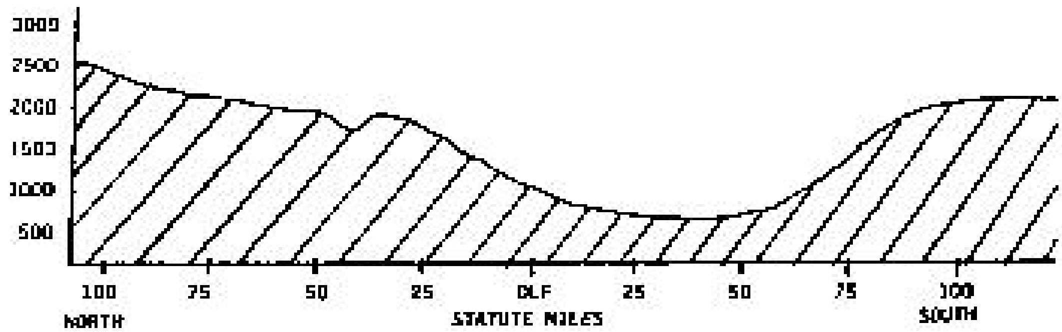

Figure 4. North to South terrain cross section with height in feet (y-axis). *Courtesy of Laughlin TFRN (1993) [can you clean these up in "Paint"?]

These storms will stay stationary unless steering flow (20,000 foot wind) is southwesterly at 25–50 knots. They will also move with the passage of a north/south oriented 500 mb trough. These types of thunderstorms have been known to cause severe weather with large hail and strong winds, and can weaken and then rebuild as they encounter moist flow over the Rio Grande Valley. (Laughlin TFRN 1993).

C. FORECASTING TECHNIQUES FOR LAUGHLIN AFB

Laughlin uses the following tools when forecasting severe weather: radiosonde observations, skew-T diagram, stability indices, freezing levels, -20 degree C isotherm heights, the AF thunderstorm checklist (See Appendix A) and the AF severe weather checklist (See Appendix B). Due to its location and surrounding environment, the base has chosen to use hand-plotted skew-T diagrams and manually calculate wind speed gusts using the Snyder Index (Ableiter 2006). This is done because current model output data that is available, North American Model (NAM), readily overestimates wind speeds by about 10 kts. The base relies heavily on satellite data, satellite derived products, and radar because of the lack of data coming from Mexico (Ableiter 2006). There are only two observation stations in Mexico, Chihuahua University and Monterrey, but their locations are too far away from Del Rio to be of great assistance (see Figure 5). Therefore, this makes forecasting the severity of storms more challenging.

The 26th Operational Weather Squadron at Barksdale AFB, LA is the unit that is responsible for issuing weather watches/warnings for Laughlin AFB. The 26th OWS responsibilities include meeting proper lead times on all advisories/watches/warnings, which range from surface temperatures to blizzards to severe thunderstorms. A chart of all lead times (ranging from 0 - 4 hours) for all events at Laughlin can be found in Appendix C. There are numerous products that the 26th OWS produces for forecasting all types of weather, ranging from surface/upper air, radar, and satellite charts, to model output including 300, 500, 700, 850, 925 mb, and surface charts. A full list of products can be found at https://ows.barksdale.af.mil.

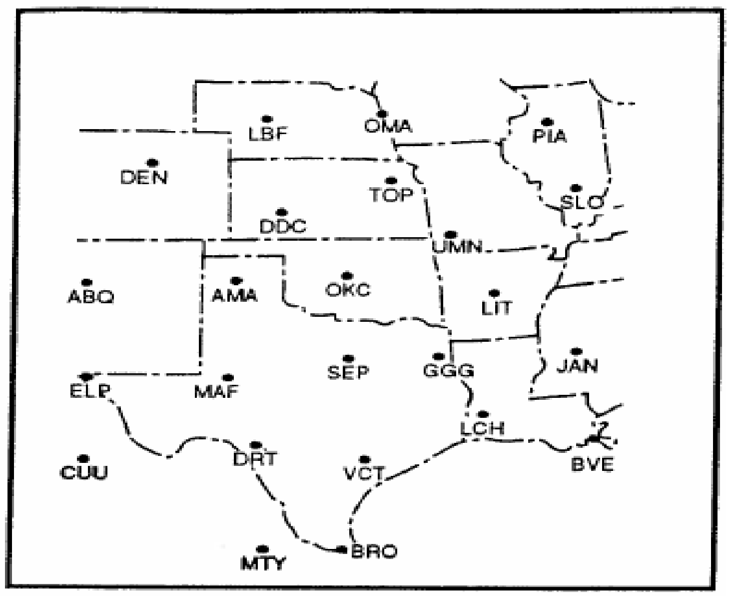

Figure 5. This figure shows the location of the two Mexican stations that are near Del Rio, TX (DRT). CUU is the station identifier for Chihuahua University, Mexico and MTY is the station identifier for Monterrey, Mexico.

D. CRAVEN AND BROOKS (2004) SOUNDING CLIMATOLOGY (SEE REFERENCES FOR TITLE)

This thesis' approach parallels the work done by Craven and Brooks (2004). Craven and Brooks (2004) created a baseline climatology of several parameters commonly used to forecast deep, moist convection using an extensive sample of upper-air observations. Their data set includes only evening (0000 UTC) rawinsonde data (approximately 60,000 soundings) from the lower 48 United States for 1997-1999. Cloud-to-ground lightning data and severe weather reports from Storm Data (Brooks et al. 1994) were used to categorize soundings as representative of conditions for no thunder, general thunder, severe, significant hail/wind, or significant tornado. Among the detailed calculations are comparisons between both convective available potential energy (CAPE) and lifted condensation levels (LCL) using a most unstable parcel versus a mean lifted 100-hPa parcel. Lapse rates for several different layers are inspected to determine the utility of using static stability versus CAPE to forecast storm severity. Lastly, low-level shear is studied in an attempt to distinguish between severe and significant tornado episodes (Craven and Brooks 2004). Their results will be discussed in conjunction with results of this study in Chapter IV.

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III. METHODOLOGY

A. GOAL OF STUDY

The goal of this study is to improve severe weather forecasting associated with convection for Laughlin AFB, TX. This will be done by using stability indices, upper air observations, i.e., sounding characteristics, and lightning data that best describes the onset of severe weather.

B. STUDY PARAMETERS

1. Geographic Location

The Del Rio/Laughlin AFB, TX region, within a radius of 30 nm, is the area chosen for this study. The radius of 30 nm (nautical miles) was chosen based on Laughlin's warning criteria threshold for all severe weather events.

2. Period of Study

The period of study for this research is from 1995–2004. This ten year data set includes upper air soundings, lightning data, and surface observations for Del Rio, TX. The months of April–September define Laughlin's severe weather season based on the average number of storms per month. The SeverePlot2 program available through the National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) Storm Prediction Center (SPC) was used to verify severe weather events that occurred in the local area within 30 nm. SeverePlot2 records hail greater than ¾'', wind gusts greater than 50 kts, and tornado events within any specified area of the continental US (CONUS).

3. Data Sources / Formats

All of the data were obtained from Air Force Combat Climatology Center (AFCCC) in raw form. The soundings were taken at 0000 and 1200 UTC, while the surface observations are hourly with special observations throughout. The lightning data was comprised of any cloud-to-ground (CG) strikes that occurred within 30 nm of Del Rio, TX.

C. HYPOTHESIS AND APPROACH

1. Hypothesis

The hypothesis guiding this research is that characteristic thermodynamic or wind features in the vertical rawinsonde measurements at Laughlin AFB are directly related to severity of convective development either at the base or in the vicinity of the base. Knowledge of these features such as wind shear, CAPE, lifted condensation level, and lapse rates can then be used to better interpret on future observed soundings, Numerical Weather Prediction forecast soundings or satellite sounding retrievals for the better forecast severe weather at Laughlin AFB.

2. Approach

The approach of this study is similar to that of Craven and Brooks (2004); however, there are some differences to note. First, the dataset is over a ten year period, 1995-2004, compared to their 3 year period, 1997-1999. Second, the dataset is for one location only, Laughlin AFB, not over the entire 48 lower United States. Third, we used sounding data from 0000 and 1200 UTC, not just the 0000 UTC. Fourth, the decision was made to only use +/- 3 hours from the 0000 and 1200 UTC soundings. This includes any convection that occurred during 2100-0300 UTC and 0900-1500 UTC. The rationale was to improve accuracy of the statistics using a technique also used by Craven and Brooks (2004). Lastly, the five convective categories used are somewhat different from Craven and Brooks (2004).

3. Data

The data used to compile weather events include, the SeverePlot2 program (defined below), surface observations, and lightning.

a. SeverePlot2

The first step in compiling our data set is to identify all severe weather that occurred in our study area. The SeverePlot2 program is used to collect this data. This program is available from the Storm Prediction Center and records all severe weather events, based on the following thresholds; hail greater than ¾’’, wind gusts greater than 50 kts, and tornado events within any specified area of the continental US (CONUS). Once this is collected, the binning of all other weather events is accomplished.

b. Surface Observations

The surface observations are binned into the following three categories, no convection, light convection, and moderate convection based on the following characteristics, wind, precipitation, and special observations including hail and thunderstorms (TS). Unfortunately, there were no records for < ¾" hail and only about 20 observations of TS for our ten year dataset. This made it difficult to identify the convective events. Therefore, the lightning data (see below) was used to verify that all the significant events were associated with convection.

If there were two or three different parameters that occurred within the same sounding period, the stronger or more severe event was used, i.e. 2200 UTC records 30 kt winds while 0100 UTC records 60 kt winds, this sounding period would be classified into SEVERE, not LIGHT. It is important to note that no sounding was moved to a less severe category.

c. Lightning

The lightning data were comprised of any cloud-to-ground (CG) strikes that occurred within 30 nm of Del Rio, TX, and were received from AFCCC courtesy of Vaisala (for further information on the lightning detection systems used - http://www.vaisala.com). AFCCC purchases the lightning data from Vaisala Thunderstorm which is the lightning-specialty business within the Vaisala Measurement Systems group. Vaisala also operates the Network Control Center for the U.S. National Lightning Detection Network® (NLDNT).

The lightning was analyzed to locate convection that occurred within the vicinity of the base and to verify that all weather events are associated with convection. In order for a sounding to be placed into the convection within vicinity category (CONVIC) the sounding needs to fall into the NONE category first, lightning then has to occur within the 30 nm radius. The lightning data was also binned by year, month, and hour to see when and where peaks of convection occurred. The following characteristics were also computed: number of strikes per hour, number of strikes per minute, number of strikes per sounding period (6 hours). These graphs can be found in Chapter IV - Results.

d. Formation of Categories

The severe convection category (SEVERE) was formed by taking all data form the SeverePlot2 program and all surface observations that had occurrences of severe weather, wind (> 50 kts), hail > ¾", and TS+. All 37 events were then compared to the lightning data to ensure that lightning had occurred during each event. This verified that there was convection present. This combination of the three data sources reduced the total number of severe events to 21. See Table 1.

The moderate convection category (MODERATE) was created by binning the surface observations according to wind (35 < 50 kts), precipitation (RA+ or hail < ¾"), and thunder (TS). The moderate category initially had 20 events. The lightning data were then used to verify the presence of convection and the resulting total was 13 cases. See Table 1.

The light convection category (LIGHT) was created by binning the surface observations according to wind (20 < 35 kts), precipitation (RA or RA-), and thunder (TS-). The light category initially had 360 events. The lightning data were then used to verify the presence of convection and that reduced result the total to 119 cases. See Table 1.

The no convection category (NONE) was created by binning the surface observations according to wind (0 < 20 kts), precipitation (none), and thunder (none). NONE had a total number of 2721 cases. See Table 1.

The convection within vicinity category (CONVIC) was established because there days where Laughlin had recorded no convection but there was still lightning event that occurred within 30 nm. CONVIC had a total number of 405 cases.

	NONE	LIGHT	CONVIC	MODERATE	SEVERE
Lightning	N/A	N/A	ANY	N/A	N/A
Winds	0-19kts	20-34kts	N/A	35-49kts	>50kts
Precipitation	none	RA - or RA	N/A	RA + or hail (GR) <3/4"	hail (GR) >3/4"
Thunder	none	TS -	N/A	TS	TS+

Table 1. The five convective categories into which all the observations are binned.

e. *Upper Air Observations - Soundings*

Upper air observations were used to compile a list of indices that would help best predict the onset of convection. The following indices were chosen: K Index, Total Totals Index, Lifted Index, Showalter Index, SWEAT (Severe Weather Threat) Index, and CAPE (Convective Available Potential Energy). These indices were chosen because they are the most widely used indices in weather forecasting, and are readily produced from soundings or model data. These indices were used along with the following sounding parameters: 700-500 mb lapse rate, Lifted Condensation Level (LCL) and Mean Layer LCL heights, 0-2 km bulk shear, 0-6 km bulk shear, and Mean Layer CAPE (MLCAPE). These parameters were chosen because they follow previous work done by Craven and Brooks (2004).

D. QUALITY CONTROL

The upper air observations or soundings were manually quality controlled. Incomplete data (resulting from abbreviated rawinsondes, missing sounding data, missing index values, etc.), erroneous data (resulting from unrealistic temperatures, winds, etc.), and garbled information (missing a “Z” after the time, etc.) were corrected and evaluated if possible.

Soundings were also removed for two primary reasons: most unstable convective available potential energy (MUCAPE) less than 150 J kg^{-1} (to allow for computation of CAPE; Brooks et al. 1994) or soundings that did not exceed 300 mb (chosen to eliminate outflow-contaminated soundings; Brooks et al. 1994). Soundings with MUCAPE less than the convective inhibition (represented by the negative area as a parcel is lifted on a thermodynamic chart), were also removed. The following thresholds were used by both Craven and Brooks (2004) and this research: lapse rates above 11^{o}C km^{-1} in the 0-2 km AGL layer and those above 10.2^{o}C km^{-1} in the 0-6 km AGL layer and the 700-500 hPa layer, 0-2 km (0-6 km) bulk shear values > 50 m s^{-1} (100 m s^{-1}).

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IV. RESULTS

The results will be organized into four sections: lightning, indices, sounding parameters, and parameter combinations. An index is calculated using mandatory levels of a sounding, while the sounding parameters, like the convective available potential energy (CAPE), are more complex typically using information from the entire sounding. The results do show some similarities and differences to the larger Craven and Brooks (2004) study. Their results will be discussed concurrently with ours.

A. LIGHTNING

The Laughlin lightning data results are presented as the distribution of lightning strikes by year, month, and hour. Also included is a table that shows the average number of strikes per hour, per minute, and per sounding period (6 hour period) for the five convective categories.

Figure 6 shows the number of lightning strikes by year. The last three years in the ten year data set, 2002–2004, show a higher number of strikes, exceeding 30,000 per year, compared to the previous seven years, averaging about 18,000 strikes per year. This is due to the U.S. National Lightning Detection Network® (NLDNT) undergoing a system-wide upgrade since spring of 2002 to increase sensor reliability and enhance the detection efficiency (Cummins, 2002).

Figure 7 shows the total number of lightning strikes per month over the ten year data set. This figure shows the large variation in the number strikes per month from 1995–2004. For example, June 1996 has fewer than 500 strikes while June 1997 has more than 16,000. We see this variation throughout the ten year dataset. This may be attributed to many factors, such as variations in the large scale flow associated with ENSO (El Niño-Southern Oscillation) or other circulation anomalies.

Figure 8 shows the total number of lightning strikes by hour. One would expect to see typical diurnal cycle throughout the day with lightning strikes, associated with convection, peeking at around 1600 local time. The Laughlin results are somewhat different as there are two peaks of lightning at 0400 and 2200 UTC. Laughlin's local time is 6 hours behind UTC, meaning these peaks are 1600 and 2200 local time. The second peak may be attributed to the storms forming to the west of Laughlin over the Burro Mountains. There may be an eastward advection of the storms during the evening. This figure also shows the low frequency of lightning in the early morning around 1200 UTC, likely due to the increased vertical stability with nocturnal cooling.

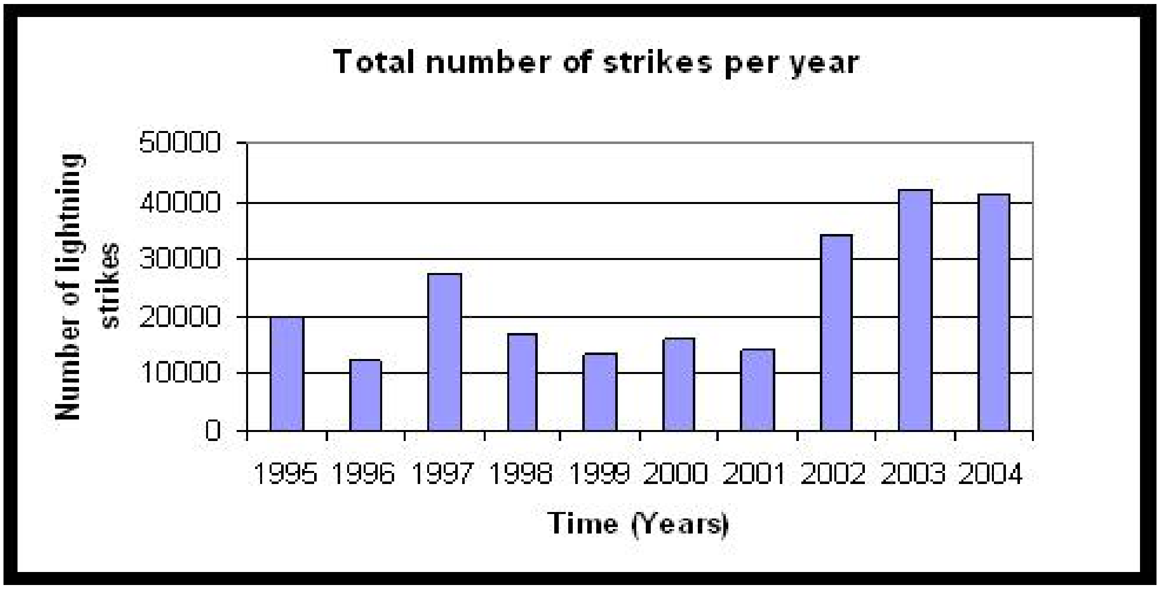

Figure 6. Total number of lightning strikes per year from 1995–2004.

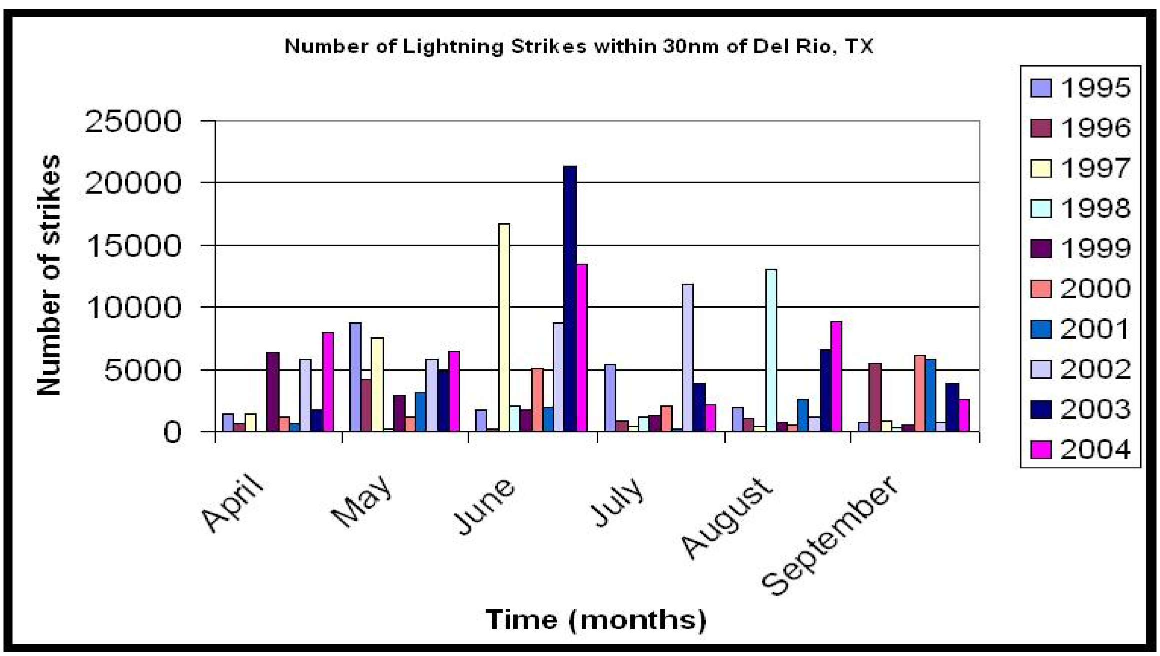

Figure 7. Total number of lightning strikes per month from 1995–2004.

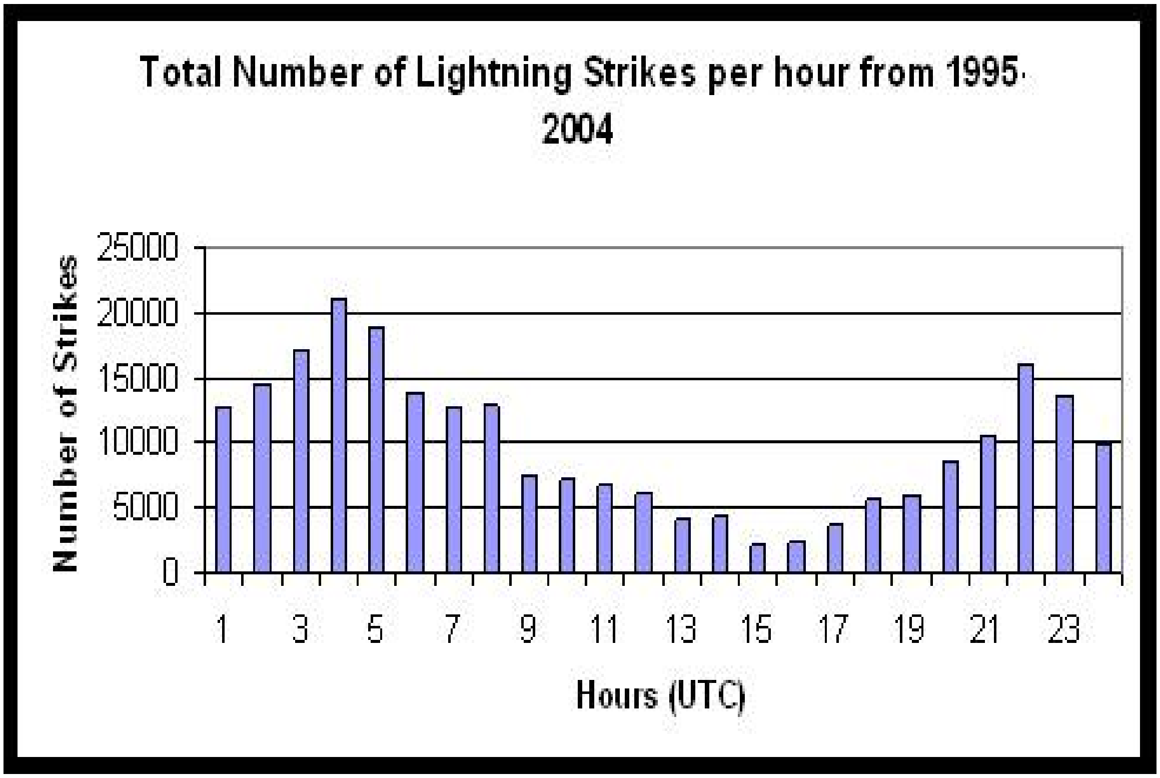

Figure 8. Total number of lightning strikes per hour from 1995–2004.

Table 2 shows the average number of strikes per hour, per minute and per sounding period over the five convective categories. The average number of strikes per hour is calculated by taking the sum of the strikes for each storm and dividing by the number of hours each storm lasted. The average number of strikes per minute is calculated by dividing the average number of strikes per hour by 60. The average number of strikes per sounding period is calculated by taking the sum of the strikes for each storm and then dividing by the total number of storms for each convective category.

Lightning Statistics	NONE	LIGHT	CONVIC	MOD	SEVERE
SPH (avg.)	0	68.8	31.4	184.6	140
SPM (avg.)	0	1.15	0.52	3	2.33
SPS (avg.)	0	269	114	909	544

Table 2. This table shows the average number of strikes per hour (SPH), average number of strikes per minute (SPM), and average number of strikes per sounding period (SPS) over the five convective categories.

The moderate and severe categories do have a higher strike rate than the light category, but an interesting feature is that the most lightning strikes and the highest strike rate are associated with the moderate category. Typical flash rates for CG strikes in non-severe storms average up to ~ 2 min^{-1} but can peak around 10 min^{-1} (Lang 2000). Our results indicate that all of the convective events do have approximately similar flash rates of 1-3 min^{-1}. Lang (2000) found that severe storms tend to have flash rates similar to the non-severe storms but extreme severe storms can exhibit flash rates as high as 20 min^{-1}. Our severe events do indicate an average similar to the non-severe events and do not have peaks as high as 20 min^{-1} but rather peak at 5 min^{-1}.

B. INDICES (SEE APPENDIX D FOR DEFINITIONS)

1. K Index

The K index is a measure of thunderstorm potential based on the vertical temperature lapse rate, and the amount and vertical extent of low-level moisture in the atmosphere. Since the K index includes the dewpoint depression (i.e., difference between the temperature and dewpoint temperature) at 700 mb, dry air will cause a lower K value. However, given moisture below 700 mb, weak stability, and a lifting mechanism, strong or severe organized thunderstorms, and even heavy rain, can still occur. (NOAA 2006)

The K Index is acknowledged not to be a useful tool in severe weather forecasting for Laughlin AFB. Results from this dataset agree with the assessment (Figure 9).

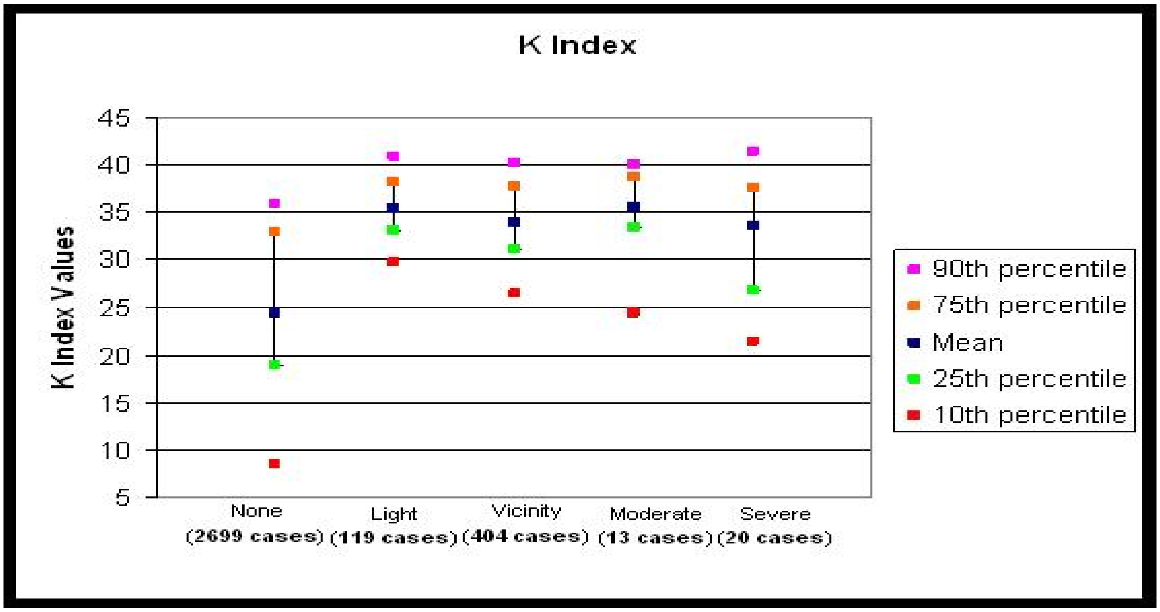

Figure 9. Distribution of the K Index over the five convective categories.[connect to fig].

Figure 9, similar to that of box and whisker plots, is an example of the type of graph used throughout the thesis. On a single figure, these plots show information about range, variance, and median values. The plot shows the 10th (bottom point, red), 25th (bottom of vertical line, green), 50th (middle point, navy blue), 75th (top of vertical line, orange), and 90th percentiles (top point, pink) of the particular data. The 25th percentile, or bottom of vertical line (green data point), indicates that 75 percent of the data is larger than the particular value. For example, Fig. 9 reveals that 75 percent (bottom of vertical line, or 25th percentile) of all severe events have a K Index value of slightly more than 27.

The K Index (Figure 9) shows no discrimination between the convective categories and contains much scatter. There is a difference in the K index between convective and no convective days. The Laughlin data shows the range of the K Index to be between 30 and 40 on thunderstorm days, with a mean near 35. This is in general agreement with the K Index interpretation rules in Appendix D. The AF Thunderstorm Checklist in Appendix A also shows a value for weak convection to be about 30, moderate ~ 35 to 40, and severe > 40. According to these thresholds, the results indicate that all the convective categories would on average display weak to moderate convection, which, according to Figure 9, is not the case.

2. Lifted Index

The Lifted Index (Figure 10) indicates some separation between the severe category and the other four categories. The data shows the range of the Lifted Index to be between -2 and -4 on thunderstorm days, with a mean near -3. The severe category does exhibit a more negative mean, but this still falls within the range of probable thunderstorms. The mean of the severe category is -4.6 while the means for the moderate and light categories are -3.3 and -2.5. Note that the 25th percentile of the severe category is greater than 50 percent of the other four categories. Much scatter does exist but there is an upward trend in the values from the None [change elsewhere ?] to the Severe categories. Our range of Lifted Index values is not as negative as is stated in the interpretation rules in Appendix D.

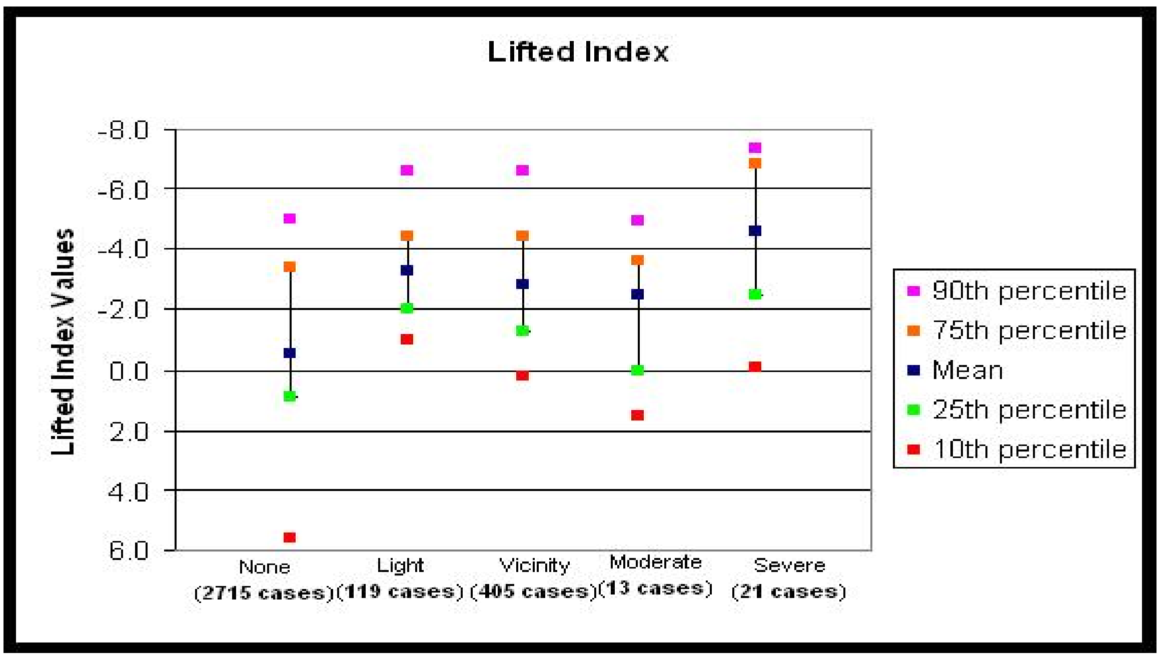

Figure 10. Distribution of the Lifted Index over the five convective categories.

The AF Thunderstorm Checklist (Appendix A) defines weak convection with values of -2, moderate ~ -4 and severe ~ -6. According to the AF Thunderstorm Checklist, the severe category mean of -4.6 would fall into the moderate convection, while the light mean of -2.5 would fall into weak convection and the moderate mean of -

3.3 would fall into weak to moderate convection. The light and moderate cases are somewhat consistent with the AF Thunderstorm Checklist while the severe events are not.

3. Showalter Index

The Showalter Index is very similar to the Lifted Index in its computation differing only in definition of the parcel used, (Showalter uses 850 mb value, See Appendix D). Therefore, the Showalter Index should have similar results to the Lifted Index which is confirmed by Figure 11.

There is some distinction between the severe category and the other categories. We see that the 25th percentile of the severe category (75 percent of the values) is greater than the bottom 50 percent of the other four categories. The severe mean is -4 while the moderate and light means are -2.3 and -2.5. The no convection has a mean of near zero. The light and moderate means around -2.5 do indicate a high potential of thunderstorms, while the severe mean of -4 indicates heavy thunderstorms, which is in agreement with the interpretation rules in Appendix D. The Showalter Index is not included in the AF Thunderstorm Checklist (Appendix A).

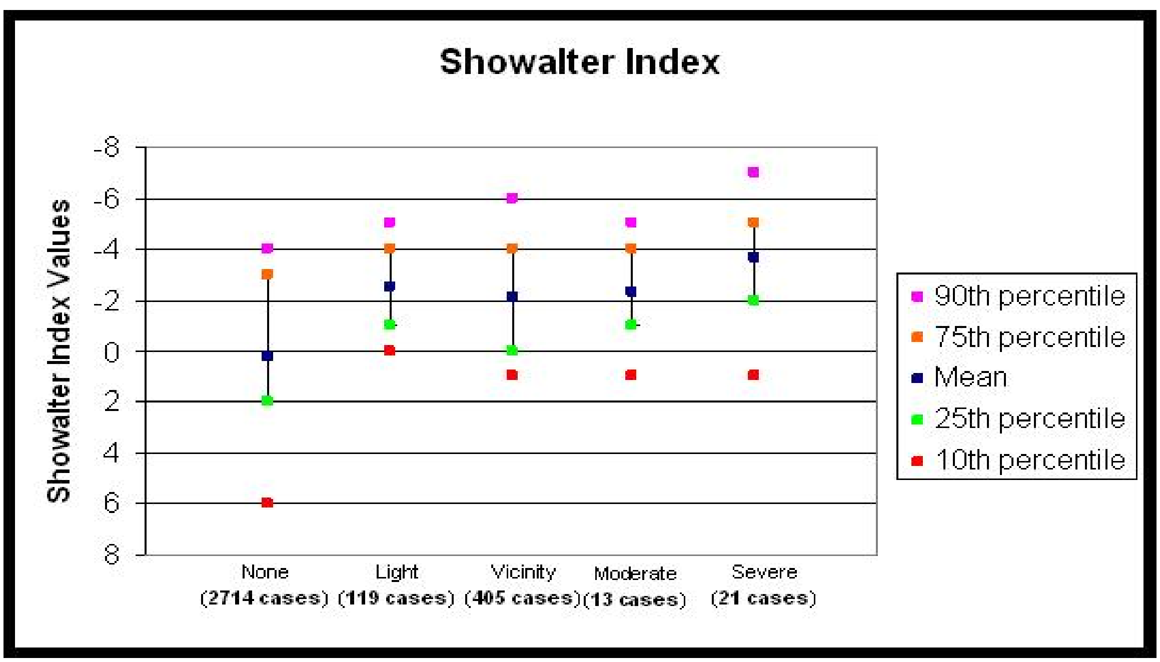

Figure 11. Distribution of the Showalter Index over the five convective categories.

4. Total Totals Index (TTI)

TTI accounts for both static stability and 850 mb moisture, but would be unrepresentative in situations where low-level moisture resides below the 850 mb level (NOAA 2006). Convection may be inhibited despite a high TTI value if a significant capping inversion is present, which can be frequently found in the Del Rio area, indicating that the TTI may not be a useful index to use.

The TTI (Figure 12) shows as much scatter as the Lifted and Showalter indices, but still indicates a very clear upward trend from the none to severe categories. The results show a minor distinction between the moderate and severe categories. The mean of the severe category is about 52.4 while the mean of the moderate and light categories are 49.7 and 48.7. The 25th percentile of the severe category (75 percent of the values) is greater than at least 50 percent of the other four categories. The middle 50 percent of the moderate, vicinity, and light categories fall between 46-52 which, according to NOAA Checklist (Appendix D), would indicate scattered to severe storms, while the severe middle 50 percent falls between 49-56 which, according to the NOAA Checklist (Appendix D), would indicate either scattered-numerous thunderstorms or isolated tornadoes. The severe category is in general agreement with the TTI interpretation rules in Appendix D, while the light, moderate, and vicinity categories are not.

The AF Thunderstorm Checklist (Appendix A) also breaks the TTI into weak (50), moderate (50 to 55), and severe (>55) convection. Our results show that the light and moderate categories would on average, according to the AF Thunderstorm Checklist, indicate weak convection, while the severe category, according to the checklist, would indicate moderate convection, which as shown in Figure 12, is not the case.

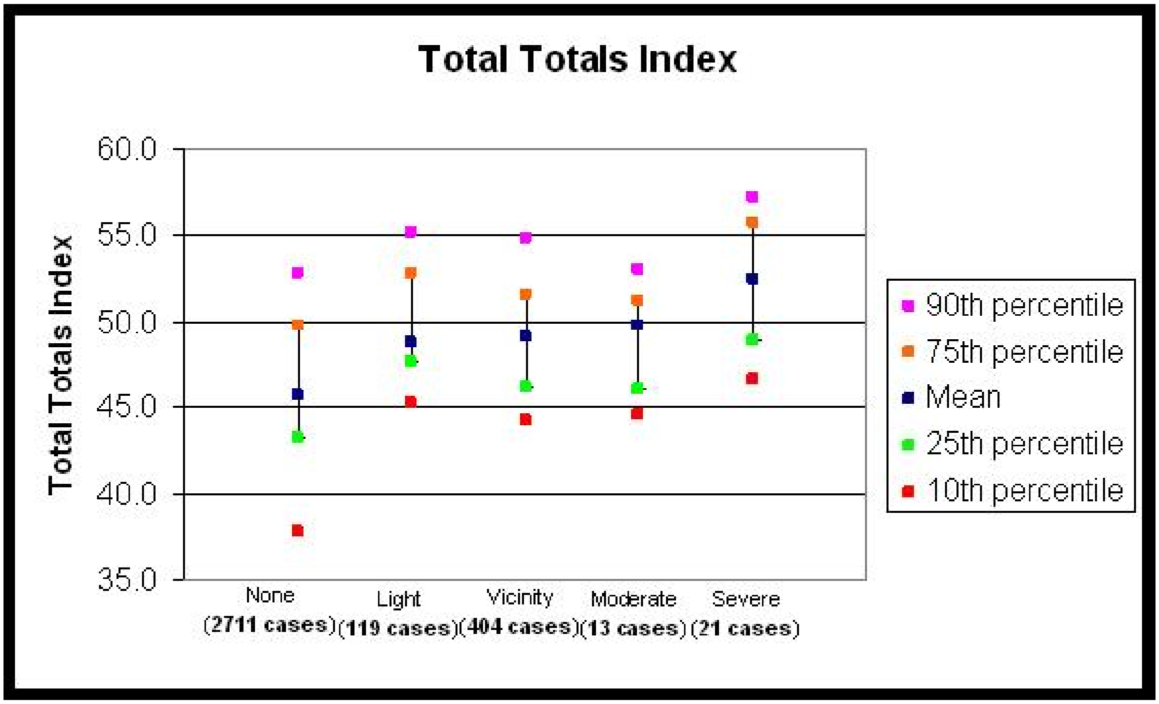

Figure 12. Distribution of the Total Totals Index over the five convective categories.

5. Severe Weather Threat Index (SWEAT)

The SWEAT index, created by the U. S. Air Force (NOAA 2006), evaluates the potential for severe weather by combining several parameters into one index. The SWEAT should be used to assess severe weather potential, not ordinary thunderstorm potential. Therefore, the SWEAT should be a useful index for the severe weather forecast problem at Laughlin. The results displayed on Figure 13, however, show that the SWEAT is no better than the other previous indices.

Figure 13 shows at least 50 percent of the light, vicinity, and moderate values are above 250, but the guidance on using the SWEAT indicates thunderstorms are unlikely with a level < 272. Fifty percent of the severe values are over 300 which would indicate a moderate risk. A value above 400 indicates a strong risk of severe thunderstorms or isolated tornadoes (Appendix D). The SWEAT results for Laughlin show an underestimation of the threat of severe convection based on the interpretation rules in Appendix D.

The results also show that an upward weak trend is present but values are widely scattered. There is a slight jump in the mean from the moderate to severe category of about 40 units, but the data does not suggest the SWEAT index by itself can be a useful tool for severe weather assessment. The SWEAT index is not addressed in the AF Thunderstorm Checklist (Appendix A).

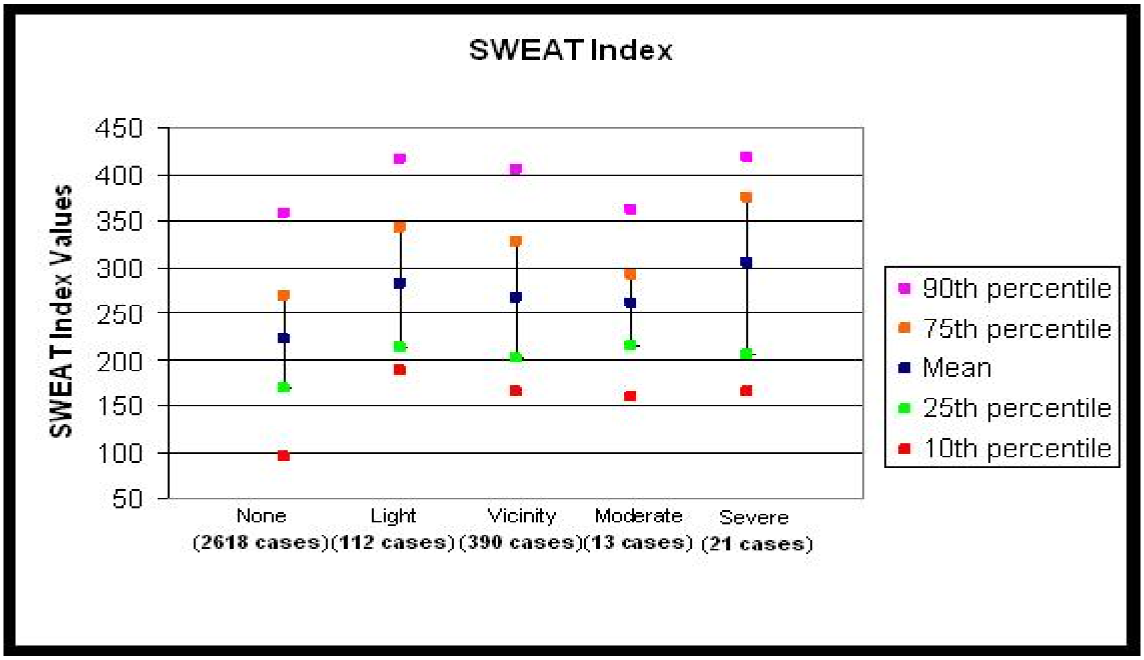

Figure 13. Distribution of the SWEAT Index over the five convective categories.

6. Most Unstable CAPE (MUCAPE)

MUCAPE provides a more complete assessment of the soundings because it involves integration over a depth of the atmosphere and is not as sensitive to specific sounding details. Also, the shape of the CAPE's profile that the parcel forms is very important as different shapes can lead to different convective characteristics due to the area between the Level of Free Convection (LFC) and Equilibrium Level (EL). The shape of the profile refers to how much positive area is located between the LFC and EL. Positive area is required for a positive CAPE value.

The results in Figure 14 show a similar upward trend in the index with respect to indices seen earlier, however, there is a larger jump from the moderate to severe category. About 75 percent of all the cases from the none to the moderate category appear to have values less than 2500 J kg^{-1} while about 70 percent of the severe cases have values above 2500 J kg^{-1}. Using 2500 J kg^{-1} as a threshold for severe convection, over 70 percent of the severe cases occur above, while about 70 percent of the moderate and light cases fall below this threshold. Even though we see that the 25th percentile of the severe category is greater than about 50 percent of the values of the other four categories, there is still too much scatter to use MUCAPE as a useful indicator by itself. (Appendix E presents a plot of the light, moderate and severe MUCAPE results including median values)

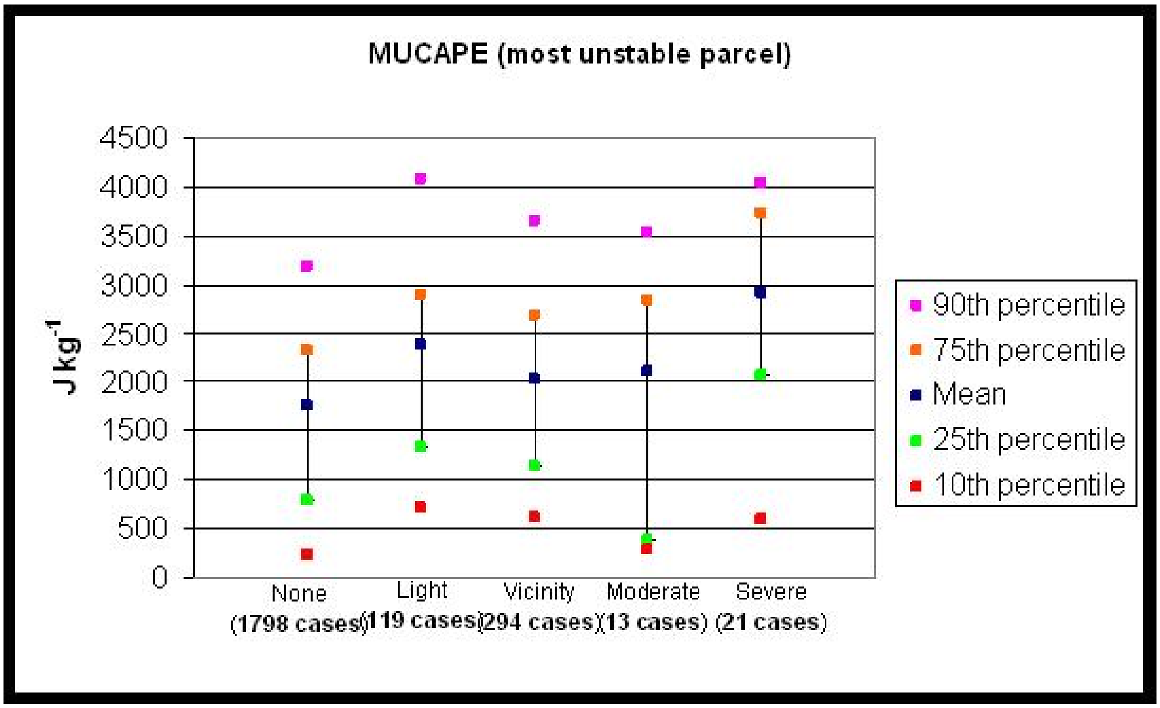

Figure 14. Distribution of the MUCAPE (J kg^{-1}) over the five convective categories.

Guidance from the NOAA Checklist (Appendix D) indicates that a MUCAPE of 2500-3000 J kg^{-1} or greater is associated with severe convection. The Laughlin results do support this guidance as the severe category has a mean of ~ 3000 J kg^{-1}. There is no separation shown in the other categories as the means of the none, light, vicinity, and moderate categories all are in the range of 1000-2500 J kg^{-1}. In fact, even the no convection cases show MUCAPE values of 1000-2500 J kg^{-1}. The severe category mean of ~ 3000 J kg^{-1} indicates very strong presence of convection, making it the only category to agree with the interpretation rules in Appendix D.

According to the AF Thunderstorm Checklist (Appendix A), CAPE from 300-1000 J kg^{-1} indicates weak convection, 1000-2500 J kg^{-1} indicates moderate convection, and 2500-5300 J kg^{-1} indicates severe convection. The only category to agree with these thresholds is the severe category. On average, all other categories could suggest moderate convection from the checklist.

C. SOUNDING PARAMETERS

1. Vertical Wind Shear

a. 0-2 km Bulk Shear

The first parameter studied was low-level shear. Craven and Brooks (2004) found low-level shear (0-1 km) to be the most striking result. The 0-1 km shear indicated that there was a clear distinction between their two most severe convective categories. 0-1 km Bulk Shear was not available for our dataset. Instead, we were able to calculate the 0-2 km bulk shear and did not find similar results. Figure 15 shows the distribution of shear for the light, moderate, and severe categories to be basically the same. The median values of the light and moderate events are 6 m s^{-1} while the severe event median is slightly higher at 7 m s^{-1}. The mean values of the moderate and severe categories were the same at 7 m s^{-1}. Overall, the 0-2 km bulk shear is not useful. (See Appendix E for a plot of individual cases of 0-2 km bulk shear by category)

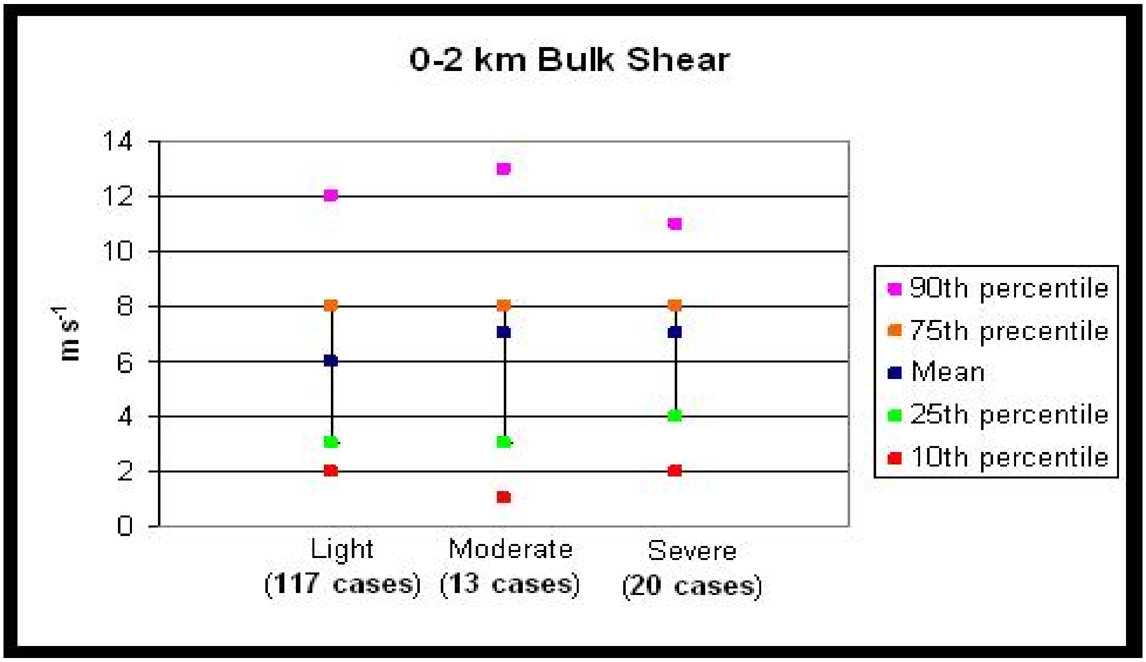

Figure 15. Distribution of 0-2 km Bulk Shear (m s^{-1}) over the light, moderate, and severe categories.

b. 0-6 km Bulk Shear

Since the 0-2 km bulk shear provided no category separation, 0-6 km bulk shear was studied. Our study shows that deep layer shear increases with convection intensity (Figure 16) and a consistent upward trend among the light, moderate and severe categories. The mean values of the light and moderate categories are 14 m s^{-1} and 17 m s^{-1}, while the severe category has a mean value of 19 m s^{-1}. The median values of the light and moderate are 12 m s^{-1} and 13 m s^{-1}, while the severe median is 20.5 m s^{-1}.

Using 10 m s^{-1} as a lower threshold for forecasting severe convection (Craven and Brooks 2004), our results indicate 85 percent of the severe and moderate events have 0-6 km bulk shear greater than 10 m s^{-1}, while light events yield values 65 percent to be greater than 10 m s^{-1}. The 10 m s^{-1} threshold does not appear to be a useful threshold for our study. Moving the threshold to 15 m s^{-1} for severe events is more appropriate for the Laughlin area.

Using 15 m s^{-1} yields better discrimination between the moderate and severe events, although much scatter does exist between the three categories. About 70 percent of the severe events have shear values greater than 15 m s^{-1}, while 62 percent of the moderate events indicate less shear, making the 0-6 km bulk shear threshold of 15 m s^{-1} a somewhat useful tool. (See Appendix E for a plot of individual cases of 0-6 km bulk shear by category)

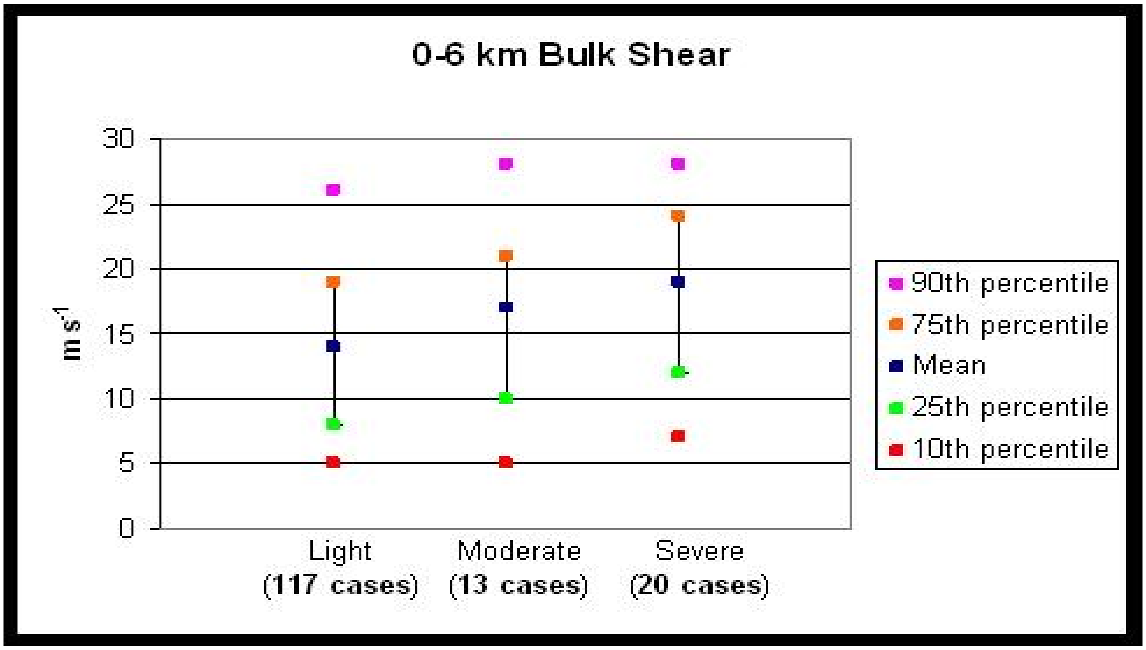

Figure 16. Distribution of 0-6 km Bulk Shear (m s^{-1}) over the light, moderate and severe categories.

2. LCL and MLLCL Heights

a. Lifted Condensation Level - LCL

Recent research by Rasmussen and Blanchard (1998) and Edwards and Thompson (2000) indicated that there is a relationship between severe convection and relatively high boundary layer relative humidity, which can be represented by low LCLs. The results of their studies showed that severe events have on average a lower median LCL height, of about 500 m, compared to moderate events. Our research showed similar results.

Our study found that when comparing moderate and severe events, severe events had on average a lower LCL height of about 600 m. The median value for moderate events is 2035 m Above Ground Layer (AGL), while severe events have a median height of 1285 m AGL. Unfortunately, the results also show that there is little distinction between the light and severe categories with mean values being 1485 m AGL and 1317 m AGL respectively (Figure 17). (See Appendix E for a plot of individual cases of LCL height by category)

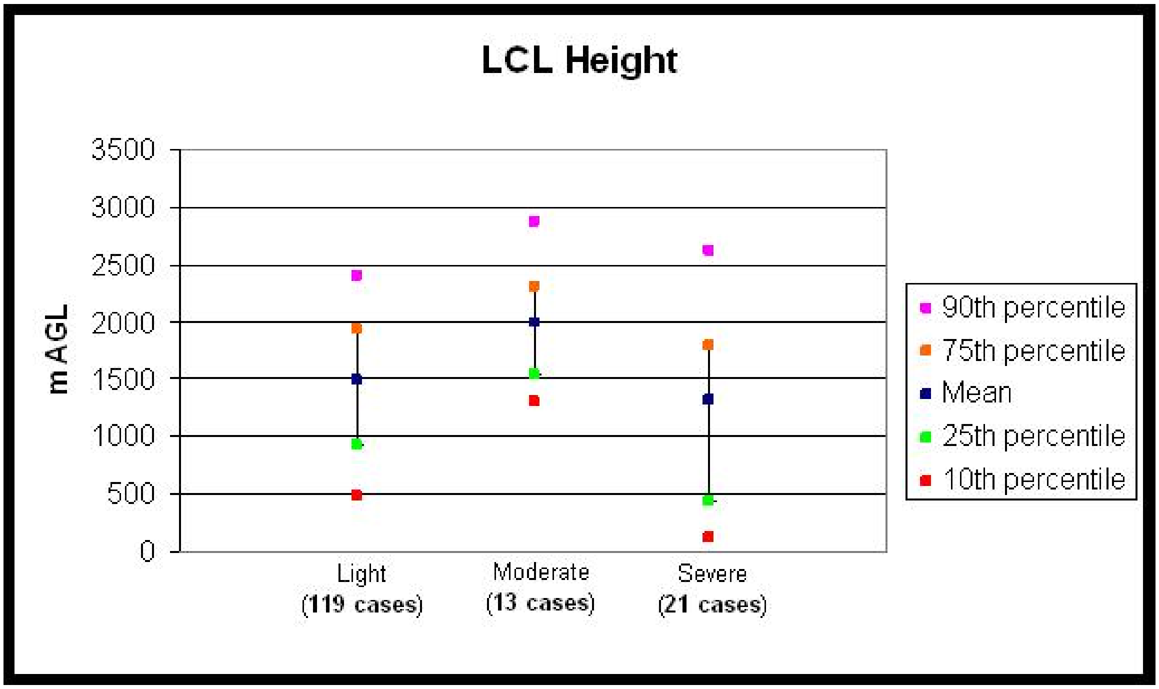

Figure 17. Distribution of the LCL height (m AGL) for the light, moderate, and severe categories.

b. Mean Layer Lifted Condensation Level - MLLCL

Craven and Brooks (2004) found that a MLLCL height of 1200 m AGL was a threshold for distinguishing between their two most severe categories. Our study shows that the MLLCL is not very useful in distinguishing between the three categories (Figure 18). Median values in our study ranged from 1544 m AGL for light events, 1757 m AGL for moderate events and 1479 m AGL for severe events. Our study showed a difference in the means of only 100-300 m, less than the 500 m reported by Craven and Brooks (2004). Severe events had a mean value of 1538 m AGL, while the moderate and light event means were 1638 m AGL and 1581 m AGL respectively. (See Appendix E for a plot of individual cases of MLLCL height by category)

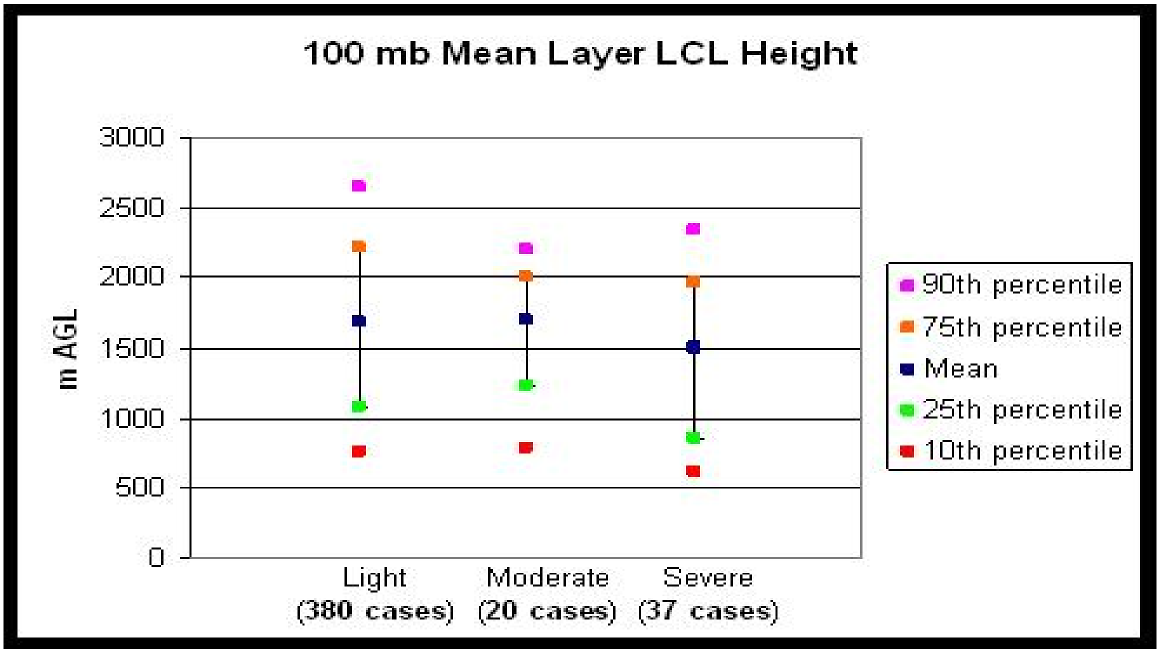

Figure 18. Distribution of the MLLCL height (m AGL) for the light, moderate, and severe categories.

3. Instability / lapse rates

a. Mean Layer CAPE –- MLCAPE

MLCAPE was chosen for analysis because Craven (2002) suggested that the mean layer parcel provides the most accurate estimate of convective cloud bases and a better representation of the boundary layer, and thus, the parcel path.

In this dataset, the mean and median values of MLCAPE do not necessarily increase with increasing intensity of deep convection (Figure 19), as the light events have a higher mean and median than the moderate events. There is also considerable overlap in the distribution. When convection is present, more than 50 percent of light and moderate events had less than 1500 J kg^{-1}, while 38 percent of the severe events were less than 1500 J kg^{-1}. Likewise, about 85 percent of the light and moderate events were less than 2500 J kg^{-1}, while the severe events had about 38 percent of the values above 2500 J kg^{-1}. The median values of the light and moderate events were 1336 J kg^{-1} and 816 J kg^{-1}, while the median value for the severe events is a little higher at 2097 J kg^{-1}. (See Appendix E for a plot of individual cases of MLCAPE by category)

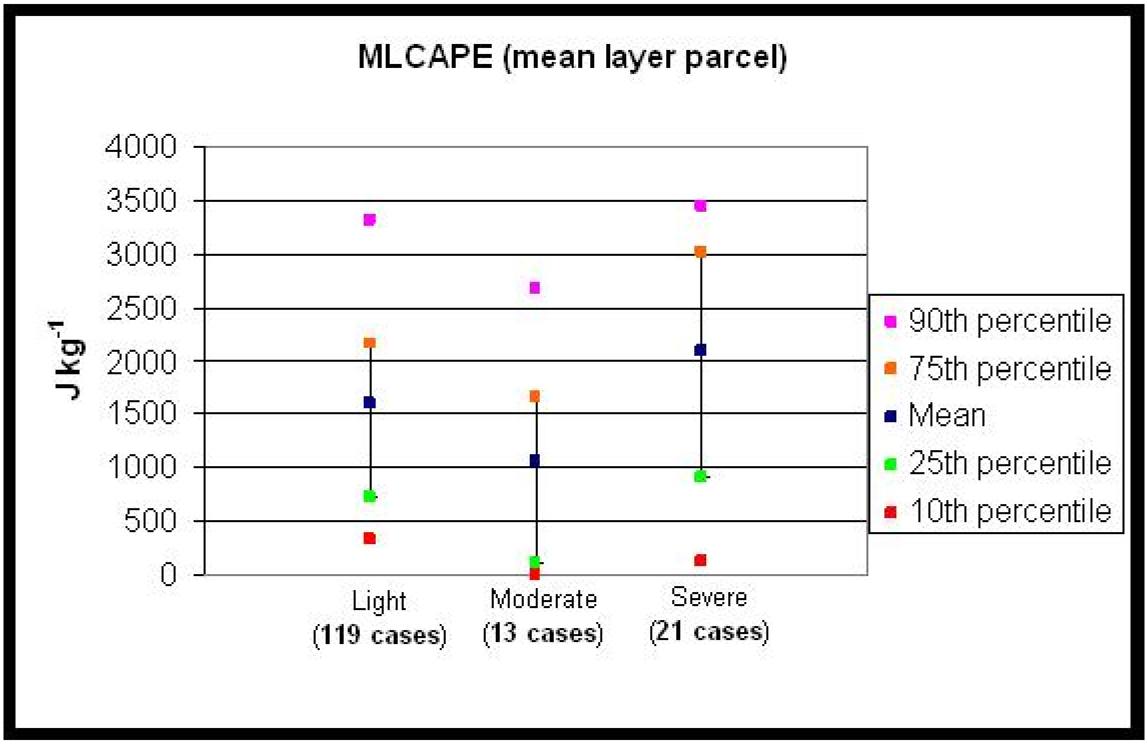

Figure 19. Distribution of the MLCAPE (J kg^{-1}) over the light, moderate, and severe categories.

b. 700-500 mb Lapse Rate

It has been shown that steeper mid-level lapse rates tend to be associated with severe convection (Carlson 1983; Lanicci 1985; Lanicci and Warner 1991a, b, c; and Craven and Brooks 2004). Our research showed that the lapse rate was a rather effective tool in showing some discrimination between the severe events with the moderate and light events (Figure 20). While the light and moderate categories show medians of the lapse rate to be 6.5°C km^{-1} and 6.7°C km^{-1}, the severe median is 7.5 °C km^{-1}. Over 67 percent of severe events occur with a lapse rate at or above 7.0°C km^{-1}, while moderate and light events have values that occur below 7.0°C km^{-1} 31 and 39 percent of the time respectively. About 52 percent of severe cases occur when the lapse rate is greater than 7.5°C km^{-1}, while 85 percent of the moderate and 71 percent of the light events show more stable lapse rates. (See Appendix E for a plot of individual cases of 700-500 mb lapse rate by category)

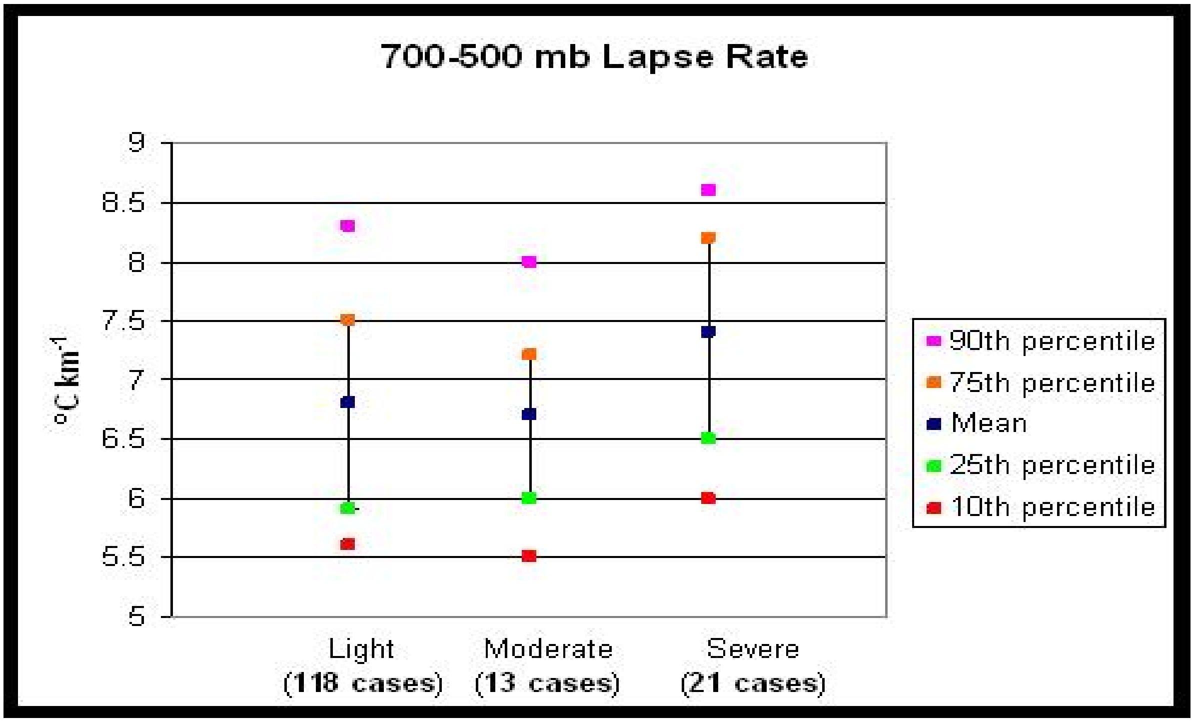

Figure 20. Distribution of 700-500 mb lapse rate ($^{o}C\ km^{-1}$) over the light, moderate, and severe categories.

D. PARAMETER COMBINATIONS

Since the results from index and sounding parameter calculations did not reveal clear separations among the convective categories, combinations of parameters are now evaluated.

1. 0-2 km Bulk Shear versus MLLCL Height

The first parameter combination that is evaluated is low level shear versus the MLLCL height. Craven and Brooks (2004) saw thresholds to be 10 m s^{-1} of the 0-1 km bulk shear and 1200 m AGL for the MLLCL for their most severe events. Their thresholds were based on the 0-1 km shear, which in their study resulted in distinguishing between their two most severe categories.

Examining 0-2 km bulk shear and MLLCL heights from our dataset does not yield useful results. Figure 21 presents a plot of these parameters and one can quickly see there is too much scatter to detect separation. The median values of the moderate and severe events are very similar with moderate events yielding a 0-2 km bulk shear of 6 m

s^{-1} and a MLLCL height of 1757 m AGL, while severe events yield a 0-2 km bulk shear of 7 m s^{-1} and a MLLCL height of 1479 m AGL.

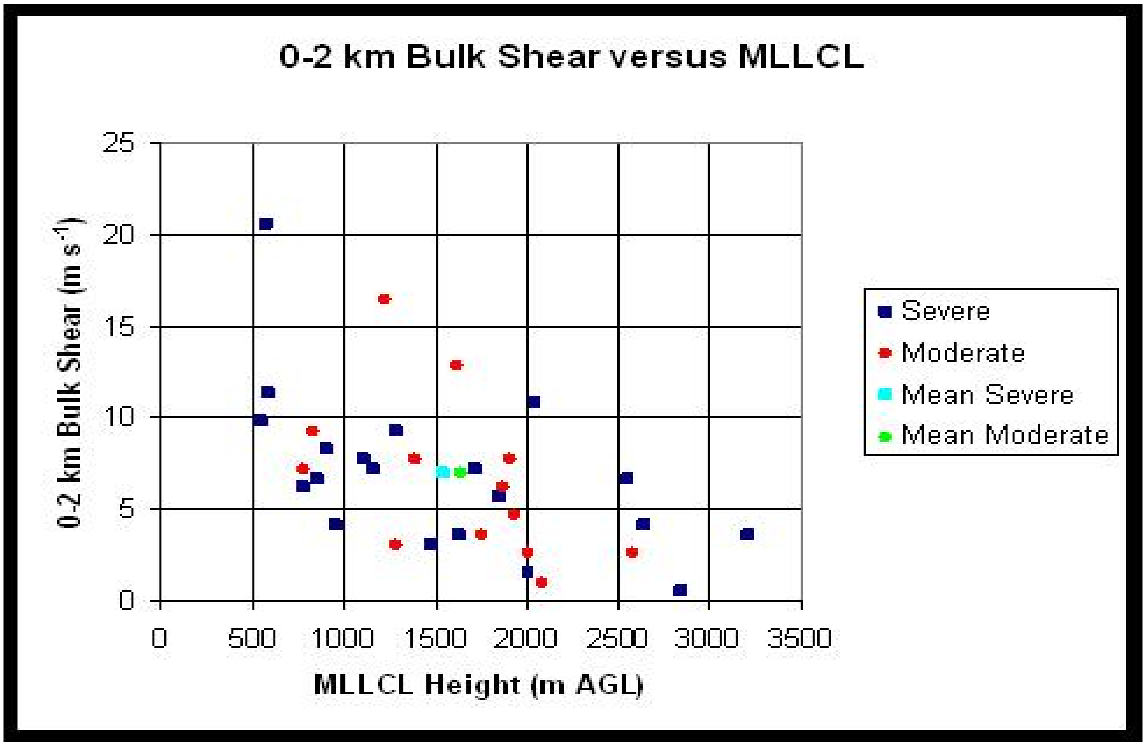

Figure 21. Scatter plot of 0-2 km Bulk Shear (m s^{-1}) versus MLLCL height (m AGL) for moderate (circles) and severe (squares) events.

2. 0-6 km Bulk Shear versus MLLCL Height

If we replace the low-level shear values with a 0-6 km bulk shear, we find a combination that does yield a better result. The median values of the moderate events are 1757 m AGL and 13 m s^{-1}, while the severe events have medians of 1479 m AGL and 20.5 m s^{-1}. Figure 22 plots this combination and illustrates that there is a separation between moderate and severe events. Over 66 percent of the severe events occur with relatively high 0-6 km shear (e.g., >15 m s^{-1}) and relatively low MLLCL heights (e.g., < 1800 m AGL), while over 62 percent of moderate events tend to have weaker 0-6 km bulk shear (e.g., < 15 m s^{-1}) and about 40 percent have higher cloud bases (e.g., > 1800 m AGL).

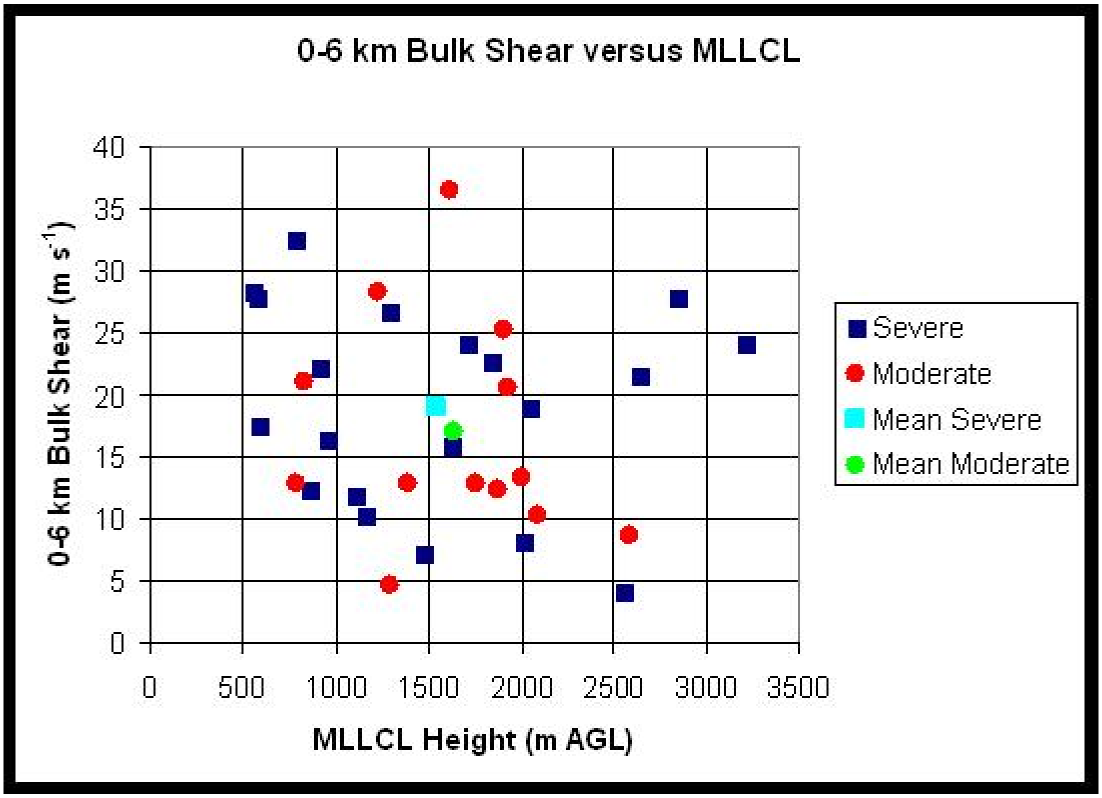

Figure 22. Scatter plot of 0-6 km Bulk Shear (m s^{-1}) versus MLLCL heights (m AGL) for moderate (circles) and severe (squares) events.

3. 0-6 km Bulk Shear versus MLCAPE

If we replace the MLLCL height with the MLCAPE in a combination of 0-6 km bulk shear, there also is a division between moderate and severe events (Figure 23), even though scatter still exists. The median values for the moderate events were 816 J kg^{-1} AGL and 13 m s^{-1}, while the severe events had median values of 2097 J kg^{-1} and 20 m s^{-1}. Over 62 percent of the moderate cases had values less than 15 m s^{-1}, while over 66 percent of the severe cases had values over 15 m s^{-1}. Moderate cases had over 77 percent of its values below an MLCAPE value of 2000 J kg^{-1}, while over 52 percent of the severe case values had an MLCAPE value over 2000 J kg^{-1}.

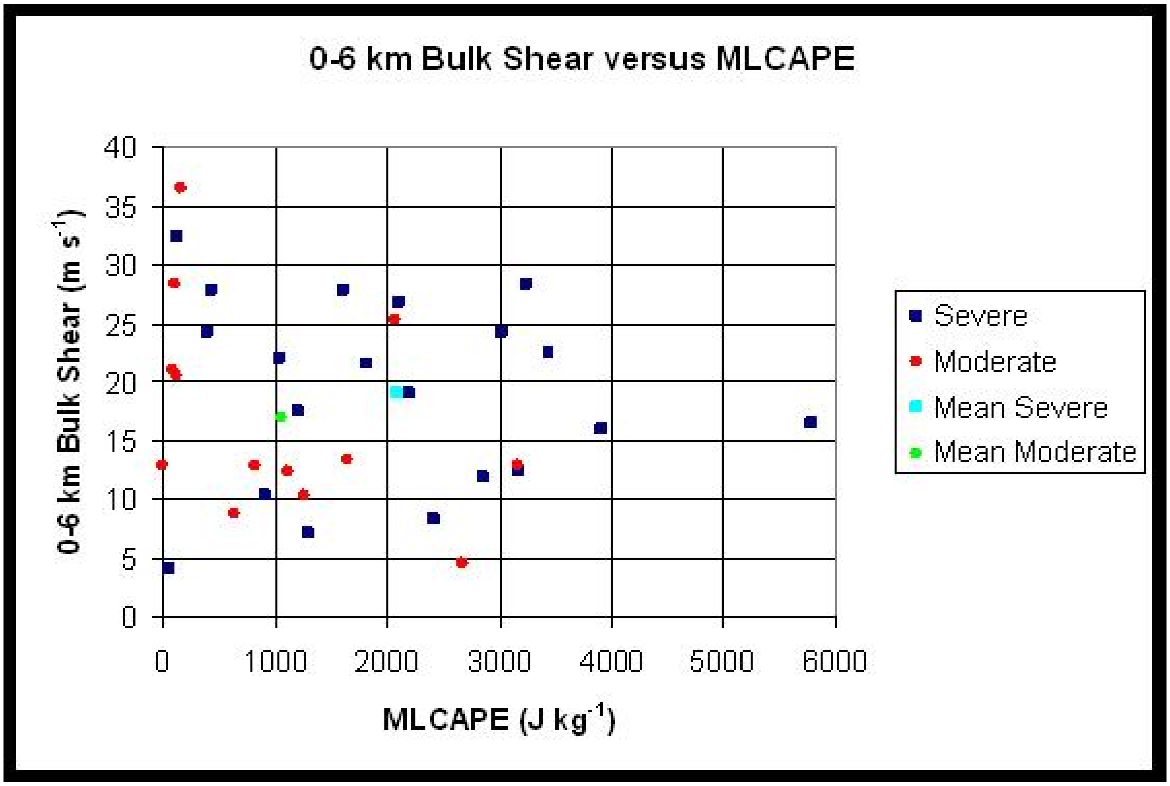

Figure 23. Scatter plot of 0-6 km Bulk Shear (m s^{-1}) versus MLCAPE (J kg^{-1}) for moderate (circles) and severe (squares) events.

4. Significant Severe Parameter

In general, individual parameters did not discriminate well between the severe and moderate events. However, previous research done by Davies and Johns (1993) and Johns et al. (1993) show that results improve when multiplying the instability and shear. They propose a significant severe parameter that does combine both instability and shear and is calculated by taking the product of MLCAPE and 0-6 km bulk shear (m^3 s^{-3}) (Figure 24).

Craven and Brooks (2004) found lower thresholds to be 10,000 m^3 s^{-3}, 20,000 m^3 s^{-3}, and 30,000 m^3 s^{-3} for their three most severe categories, while our study found possible thresholds to be 15,000 m^3 s^{-3} - 20,000 m^3 s^{-3} for the light to moderate categories, and 35,000 m^3 s^{-3} for the severe category. The median values for the light and moderate categories were 14419 m^3 s^{-3} and 10486 m^3 s^{-3}, while the median value for the severe category was 33740 m^3 s^{-3}. Over 50 percent of the severe cases are greater than 30,000 m^3 s^{-3}, while the light and moderate categories only have about 10-15 percent of their values above 30,000 m^3 s^{-3}. This parameter shows the best discrimination between the light, moderate and severe events for our dataset. (See Appendix E for additional plots of significant severe parameter by category)

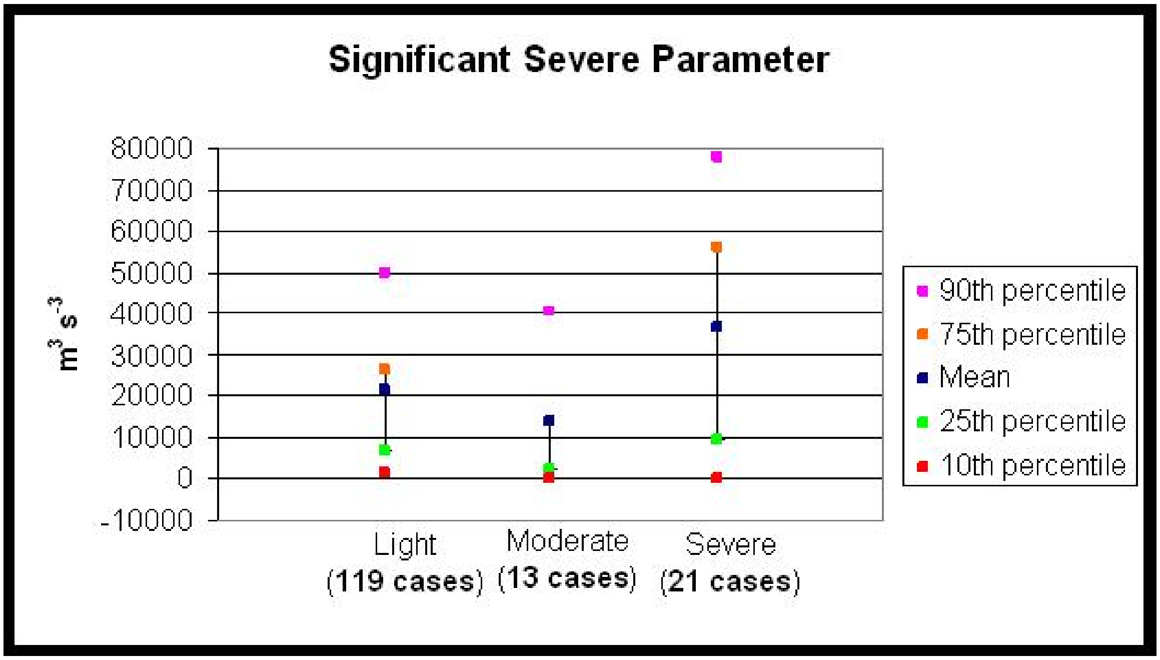

Figure 24. Distribution of the Significant Severe Parameter (m^3 s^{-3}) over the light, moderate, and severe categories.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Several conclusions can be drawn from the results of this observational study of Laughlin AFB sounding data. The most useful tools in this study were the Significant Severe Parameter followed by the 0-6 km Bulk Shear versus MLCAPE, and lastly by the 700-500 mb Lapse Rate and 0-6 km Bulk Shear by themselves. The least useful tools were the traditional stability indices.

1. Lightning and Indices

The lightning data set illustrated an hourly distribution of convection for the Laughlin forecast area, highlighting convective peaks at 0400 and 2200 UTC (1600 and 2200 local time). The dataset also showed the variability of the number of strikes per month and per year. The flash rates of the storms in this dataset are comparable to flash rates of previous research. No single index by itself is a useful tool in evaluating severe convection. There was no attempt made to combine the indices or develop a new index algorithm.

2. Sounding Parameters

a. Vertical Wind Shear

0-2 km bulk shear calculation did not show discrimination between the severe and moderate events. 0-6 km bulk shear, however, may be a useful tool by itself as it does show some separation between the moderate and severe events. Using 15 m s^{-1} as a threshold does yield better discrimination between the light, moderate and severe events, although there is scatter among the three categories.

b. LCL and MLLCL Heights

LCL height discriminates well between the moderate category and the light/severe categories. LCL height parameter does follow with previous research that the severe event LCL heights are ~ 500 m lower than moderate events (our results show ~ 600 m lower for severe events). The only drawback is that there is little discrimination between the severe and light categories in the LCL height. MLLCL height does not discriminate between the three convective categories, but when combined with the 0-6 km bulk shear does discriminate between the moderate and severe events.

c. Instability/lapse rates

The mean and median values of MLCAPE do not necessarily increase with increasing intensity of deep convection, as the light category has a higher mean than the moderate category. There is considerable overlap in the distribution, but overall there is some discrimination between the severe events from the rest of the convective events. The 700-500 mb lapse rate was a useful indicator in that it showed some discrimination between moderate and severe events. Our study shows a possible lower threshold of $7.5^{o}C\ km^{-1}$ for severe events where over 52 percent of severe cases occurred when the lapse rate was greater than $7.5^{o}C\ km^{-1}$, while 85 percent of the moderate and 71 percent of the light events yielded weaker lapse rates.

3. Parameter Combinations

The following combinations provided the most encouraging results when discriminating between the moderate and severe events.

a. 0-6 km Bulk Shear versus MLLCL Height

0-6 km bulk shear versus MLLCL height did yield some discrimination between the moderate and severe events. Possible thresholds for discriminating between the moderate and severe cases are shear greater 15 m s^{-1} and MLLCL heights below 1800 m AGL, as over 66 percent of the severe events tend to occur with relatively high 0-6 km shear (e.g., >15 m s^{-1}) and relatively low MLLCL heights (e.g., < 1800 m AGL), while over 62 percent of moderate events tend to have weaker low-level shear (e.g., < 15 m s^{-1}) and over 40 percent have higher cloud bases (e.g., > 1800 m AGL)

b. 0-6 km Bulk Shear versus MLCAPE

Examining 0-6 km shear versus MLCAPE yielded a strong division between moderate and severe events. The mean and median values (moderate and severe medians were 1068 J kg^{-1} with 13 m s^{-1} and 2081 J kg^{-1} with 20.5 m s^{-1} respectively) do clearly demonstrate the difference between the moderate and severe events even though there is large scatter in the results.

c. Significant Severe Parameter

This parameter was the most useful tool in our study yielding the greatest discrimination between the moderate and severe categories. Over 50 percent of the severe cases are greater than 30,000 $m^3\ s^{-3}$, while the light and moderate categories only have about 10-15 percent of their values above 30,000 $m^3\ s^{-3}$. Our study found possible thresholds to be 15,000 $m^3\ s^{-3}$ for the moderate events and 35,000 $m^3\ s^{-3}$ for the severe events. The mean and median values (moderate and severe medians were 10486 $m^3\ s^{-3}$ and 33740 $m^3\ s^{-3}$) clearly demonstrate the separation between the moderate and severe convective events.

B. RECOMMENDATIONS

This dataset of weather events was relatively small. The compilation and examination of a larger set of soundings (i.e., 20 or 30 year data set) to test the results of this study against would be useful. Another aspect to consider was that this study considered both 1200 and 0000 UTC soundings. The 1200 UTC sounding time naturally is more stable and lightning data shows this a time of minimal convection. Therefore, it may be of importance to focus solely on the 0000 UTC soundings as was the case in Craven and Brooks (2004). Based on the lightning results, climatology aspects (e.g. ENSO) or other circulation anomalies can be examined to determine their effects on severe convection. Finally, including more stations besides Laughlin, AFB would be valuable to study regional effects.

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APPENDIX A – THUNDERSTORM CHECKLIST

Thunderstorm Checklist from the Analysis and Forecast Program (AFP) 47 OSS/OSW Laughlin AFB, TX

This is currently used by forecasters to verify if thunderstorms will occur on base.

PARAMETER	WEAK	MODERATE	STRONG
500mb Vort	Neutral / Neg advection	Contours cross at 30 degrees	Contours cross > 30 degrees
Lifted Index	-2	-4	-6
Total Totals	50	50 to 55	>55
Cross Totals	25	25 to 30	>30
K Index	30	35 to 40	>40
KO Index	> 12	4 to 12	< 4
CAPE	300-1000	1000-2500	2500 - 5300
Mid-level Jet	35 knots	35-50 knots	> 50 knots
Shear	15k / 90 nm	15-30 knots 90nm	> 30kt / 90nm
Upper level jet	55 knots	55 - 85 knots	> 85 knots
Low level jet	20 knots	25 - 35 knots	> 35 knots
850 dew point	8 degrees Celsius	8 C to 12 C	> 12 degrees Celsius
850 max temp	East of ridge axis	Over moist ridge	west of moist ridge
700 no change line	winds cross at 20 degrees	Winds cross at 20-40 degrees	Wind cross at 40 degrees
700 dry air intrusion	N/A or weak	Winds 10-40 degrees at 15kt	Wind > 40 degrees at 25kt
12 hr sfc pressure falls	< 1 mb	1 to 5 mb	> 5 mb
500mb ht change	30 m	30 - 60 m	> 60 m
WBZ (h-feet	> 110 or < 050	090 -110 or 050 -070	070 - 090
Sfc dew point	13 Celsius	13 - 18 Celsius	> 18 Celsius
Sfc pressure	1010 mb	1010 - 1005 mb	1005 mb

Wet Bulb Zero height ___________ Forecast hail size ____________ If WBZ is > 12,500 feet = **heavy rain / hail 1/4 inch**
T1 Gust method _________ T2 Gust method __________ Vil of the day value ________ Veering vertical environment Y / N

Answer the following questions to determine initial thunderstorm outbreak locations:
Do we have moist conditionally unstable air over the forecast area? Y / N
Are there any boundaries in the area? (fronts, outflows, washed out cold fronts, trough)
Is strong upper level cold air advection occurring over the area or upstream? Y / N

Is strong low-level warm / moist advection taking place?
Locate intersection of warm, moist low-level air and strong 500mb cold air advection. __________________________
--The location depends on the speed of the cold front and the dry surge into the moist air.
The area extends along 200 miles to the right of the 500mb jet (in the diffluence)
From the dry intrusion to where the low-level moisture decreases
Locate the intersection of the low-level jet and the warm front.
Locate the intersection of the low-level jet and the 500mb jet.
Severe weather extends along and south Single updraft and downdraft core
of the 500mb jet but will be north of the 850mb warm front.
Rules of Thumb for Severe Pulse Thunderstorms
Single updraft and downdraft core
Short lived (about 1/2 hour to an hour)
Single cell thunderstorms develop in a weak vertical shear environment
--**This allows the precipitation and downdraft to fall directly back into the updraft** Echoes first appear aloft and continue to grow vertically as precipitation starts descending Severity of the pulse thunderstorm is entirely dependent upon the updraft strength
-- The first echo of a severe cell develops higher and stays aloft longer than non-severe
Wind gusts associated with outflow boundaries are the most frequent form of severe weather
Only way to warn for a pulse storm wind gust is to anticipate development
This can be done by recognizing
-- Weak vertical shear in the lowest 12,000 feet (VWP)

-- Along with high CAPE values (Positive energy areas on the Skew-T)
-- A forcing mechanism to create a strong updraft
WARNINGS SHOULD BE CONSIDERED WHENEVER 50DBZ extends above 30,000 feet
IF THE WORK SHEET LEADS TO THE CONCLUSION THAT SEVERE WEATHER IS PROBABLE FOLLOW THE SEVERE WEATHER CHECKLIST INSTEAD OF THIS THUNDERSTORM CHECKLIST! (Severe Thunderstorm Checklist must be used if the OWS is forecasting moderate or severe thunderstorms for KDLF)

APPENIDX B – SEVERE WEATHER CHECKLIST

This is the checklist used if the thunderstorm worksheet leads to the conclusion that severe weather is probable. Severe Thunderstorm Checklist must be used if the OWS is forecasting moderate or severe thunderstorms for Laughlin, KDLF.

SOP O-03R-18, SEVERE WEATHER THREAT ANALYSIS

REFERENCE: AFMAN 15-129, 26 OWS Policy, TN-98/002 and TR-200.

GENERAL: This section outlines general analysis requirements, but it is important that the forecaster be aware that these are only standard parameters used to evaluate severe weather potential. When conditions favor the development of severe weather the lead forecaster, regional manager and/or the operational forecaster/apprentice should use the procedures below.

Procedures:

a. The lead meteorologist will review the Storm Prediction Center's (SPC) graphic depiction. If any portion of the 26 OWS AOR is in a **Slight** or worse convective outlook region then the lead meteorologist will review the SPC Convective Outlook discussions and to hone in on the AOR use the JAAWIN Threat Assessment-Surface product . Additionally, there is more NAM or MM5 model data available via the Model Output link (select a level 300mb, 500mb, Surface, etc.) on left column of our webpage, then in the right column select the PCPN-TYPES.

b. Once a threat is identified the lead meteorologist and a 7-level will complete the severe thunderstorm procedures below to further refine the threat area. Once the area is refined, the lead meteorologist will instruct the impacted regional manager and operational forecaster to conduct further analysis to include: Skew-T data, instability indices, METSAT, and radar. Plus both the regional manager and operational forecaster must review any severe weather forecasting guidance and be familiar with any impacts to the supported customer as outlined in the respective base's Forecast Reference Notebook (FRN) at: AOR FRNs.

SEVERE THUNDERSTORM PROCEDURES: There must always be a lifting mechanism, fuel and a trigger to get convection. Once the potential for general convection potential has been established, then determine if there is the potential for severe weather.

1. Compile the analysis by using the following link Severe Analysis Overlays to select the Standard Parameters for Severe Weather Analysis listed below from AFMAN 15-129, table 3.4. Next use the reasoning to help identify the severe weather threat. This list is not all inclusive and

should be used with other charts/indices such as the upper air and surface analysis. Additionally, the TSTORM OVERLAY product can be used.

Standard Severe Weather Analysis Parameters (reference AFMAN 15-129 Table 3.4)

Chart	***Standard Parameters***	***Why*** (favorable/unfavorable; weak, moderate, strong chance for severe weather conditions)
200mb or 300 mb	- Streamlines and axes of diffluent winds	- Favorable for development (mass is removed from the top of the storm which intensifies the upward vertical motion within a storm)
	- Isotachs in red every 20 knots starting with 50 knots	*≤ 55 kts – **Weak**; 56 to 85 kts- **Moderate**; ≥ 86 kts – **Strong**
	- Height falls (**300mb only**) using same procedures as 500 mb	*≤ 30 m – **Weak**; 31 to 60 m- **Moderate**; ≥ 61 m – **Strong**
	- Stratospheric warm sinks/cold domes	Denotes upper level convergence (sink) or divergence (dome)
	- Circulation centers (cyclones **C**, anticyclones **A**)	Used to determine if system is barotropic or baroclinic. Aids in synoptic pattern type recognition.
500 mb	- Axes of maximum wind flow label all speed maximas	*≤ 35 kts – **Weak**; 36 to 49 kts- **Moderate**; ≥ 50 kts – **Strong**
	- Closed Highs and Lows with center height values	Closed lows destabilize the atmosphere by providing a midlevel cold pool (thus producing steep midlevel lapse rates) and Positive Vorticity Advection
	- 12-hr. height falls every 30m. If the center exceeds 180m, draw height fall isopleths every 60m. Label center with an **X** and the maximum value	*≤ 30 m – **Weak**; 31 to 60 m- **Moderate**; ≥ 61 m – **Strong** 500 mb height change, in association with the 500 mb temp change, is closely related to the 500 mb vorticity field.

	- Isotherms every $2^{O}C$ - Thermal (cold) troughs and warm/cold pockets	*Severe activity suppressed near and east of thermal ridge particularly when in phase with streamline ridge. Positive Vorticity Advection and Cold Air Advection are favorable for development Negative Vorticity Advection and Warm Air Advection are unfavorable for development
700 mb	- Flow streamlines - Axes of maximum wind flow ≥ 30 kts, label all speed maxima - Isotherms 2-degree intervals, highlight $0^{O}C$ isotherm (if applicable) - Circulation centers (cyclones **C**, anticyclones **A**) - Dry air intrusions (≥ $10^{O}C$ dew point difference) intruding into a significant moisture field (DPD < $6^{O}C$ /RH >70%)	*Confluent areas which are favorable for severe Needed to tilt a storm (displacing updraft from downdraft), allows the updraft to sustain itself for a longer period of time, allows the development of a mesocyclone, and allows rotating air to be ingested into the updraft (tornadogenesis). *Good stacking of cold air here and at 500 mb is favorable for severe. Used to identify shortwave troughs/ridges. Generally, cold air advection is found to the left of the short wave axis with warm air advection to the right of the trough axis. The $0^{O}C$ isotherm separates WAA and CAA, usually coincident with 850 mb warm ridge. If the $0^{O}C$ isotherm is ahead of mid-level trough then deepening of sfc low may occur. *Winds crossing the axis of 700-mb dry intrusions and moisture boundaries: by less than 20^{O} – **Weak**; 20^{O} - 40^{O} – **Moderate**; > 40^{O} – **Strong** A wedge of mid-level dry air (more dense) above a moist layer (less dense) is convectively unstable.
850/ 925 mb	- Streamlines and axes of confluent winds	*The greater the angle of winds from dry to moist air, the more unstable

	- Axes of maximum wind flow: $\geq$ 25 kts, label all speed maxima	Needed to tilt a storm (displacing updraft from downdraft), allows the updraft to sustain itself for a longer period of time, allows the development of a mesocyclone, and allows rotating air to be ingested into the updraft (tornadogenesis).
	- Isotherms every 2^{O}C; highlight 0^{O}C isotherm (if applicable)	The 0^{O}C isotherm separates WAA and CAA
	- Thermal ridges and warm/cold pockets.	**Position of 850 mb Max Temp field: East of moisture ridge – **Weak** Over moisture ridge – **Moderate** West of moisture ridge – **Strong**
	- Axes of Equivalent Potential Temperature (Theta-E) Ridges	In a region with adequate instability, areas of relatively high Theta-e (called Theta-e ridges) are often the burst points for thermodynamically induced thunderstorms and MCS's. Theta-e ridges can often be found in those areas experiencing the greatest warm air advection and moisture advection.
	- Isodrosotherms every 2^{O}C for values of $\geq 10^{O}$C at 925mb and $\geq 6^{O}$C at 850mb	*< 8^{O}C- **Weak**; 8^{O} - 12^{O}C– **Moderate**; > 12^{O}C– **Strong**
	- Circulation centers (cyclones **C,** anticyclones **A)**	
	- Dry air intrusions (see 700 mb)	
Surface	- Fronts, troughs, and confluent zones. Track fronts until no longer discernible	Trigger mechanism--areas of low level convergence
	- Dry lines, meso-highs, outflow boundaries, and squall lines	Trigger mechanism; squall lines could move into an area that has to potential to produce severe weather

	- Moisture ridges and axes of maximum moisture advection	*Dew point < 13^{O}C- **Weak**; 13^{O} - 18^{O}C– **Moderate**; > 18^{O}C- **Strong** Area of increased instability
	- Thermal ridges - Isallobars; highlight anallobars (pressure rises) and katallobars (pressure falls)	*Squall lines often develop in narrow troughs of falling pressure. A strong pressure rise/fall couplet is favorable for severe weather. The following values indicate probability for severe weather: $\leq$ 1 mb **Weak** 2 to 5 mb **Moderate** > 6 mb **Strong** Trigger mechanism
	- Tropical depressions, tropical storms, tropical cyclones, typhoons, or hurricanes, as required	

* - denotes source as TN-98; ** - denotes source as TR-200

2. Data Analysis:

a. Look at all the max wind flow bands.

1. Look for a slightly veering profile with height. Unidirectional flow is a negative for severe. Look for at least 30-45 degrees of veering in the lowest 4km (about surface through 700mb).

2. Look for low level wind flow bands intersecting a surface or low level front (indicates lift).

3. Compare a midlevel jet with your low level jet. If it crosses at an angle of about 30-55 degrees, then it is a positive for severe. An angle that is greater than 55 degrees will usually give too much shear. Whereas an angle less then about 30 degrees then the midlevel flow must be at least 30% stronger than the low level flow to still support severe.

b. Consider the moisture and dry air sources/axes.

1. Having a moisture ridge oriented just to the east of (or slightly superimposed on) a dry tongue is positive for severe. The moisture ridge will be at the surface through 850mb….located lower than the dry tongue.

2. A dry air intrusion will normally be located at about 700mb. A strong dry punch is a strong positive for severe.

3. No moisture source is a negative for severe.

4. Consider the effects of the next few hours on the existing moisture available. Will new sources be introduced in time to support severe?

c. Look for diffluent winds aloft especially when diffluent winds are evident in the same column from 200mb-500mb, as this indicates the full column of air is lifting. Positive for severe, but must include other factors.

d. Thermal parameters.

1. Is there is thermal ridge intersecting the area of concern at low levels? If so, then this is positive for severe.

2. Is there a theta-e ridge present in the area of concern? Apex of the ridge is positive for severe. Be sure to consult a normal horizontal graphical depiction of theta-e as well. The areas where the theta-e ridge has the strongest packing are the best areas for severe.

e. Consider mid level destabilization.

1. Are there any mid-level cold troughs approaching the area?

2. Include any max height falls approaching the area of concern.

f. Is the low level/surface set up conducive to severe?

1. Is there a front or major trough near or on the surface that will provide focus or trigger for convection?

2. Is there a low level cyclonic circulation that may cause shear lines and lift / trigger?

g. Refer to Chapter 3 in TN-98/002 to aid in synoptic pattern type recognition.

3. Once the threat potential is identified (to include the area impacted, severity of event, type of event, timing of event, etc.), then follow the guidance in SOP O-03RP-02, SEVERE WEATHER ACTION PROCEDURES (SWAP).

APPENDIX C – WATCH, WARNING & ADVISORY CHART

The 26th Operational Weather Squadron watch/warning/advisory chart with lead times for Laughlin AFB, TX

WWA Type	Category	Criteria	DLT
KDLF Laughlin AFB			
Advisory	Surface temperature	Surface temperature less than 32 F. for at least 24 hrs. is forecasted to occur at Laughlin AFB.	1:00
Advisory	wind chill is	Observed wind chill is less than or equal to 15 F. at Laughlin AFB.	0
Warning	Blizzard conditions	winds greater than or equal to 30 kts and visibility less than or equal to 1/2 mi. in snow lasting 3 hrs or longer are forecasted for Laughlin AFB.	1:30
Warning	Damaging winds	Damaging winds >= 50 kts. forecast to occur at Laughlin AFB	2:00
Warning	Freezing precipitation	Freezing precipitation is forecasted to occur at Laughlin AFB.	1:30
Warning	Hail	Hail >= 1/4 but < 3/4 in. is forecast to occur at Laughlin AFB	1:30
Warning	Hail	Hail >= 3/4 in. is forecast to occur at Laughlin AFB	2:00
Warning	Heavy rain	accumulation are greater than or equal to 3 in. within 6 hrs. is forecasted to occur at Laughlin AFB.	1:30
Warning	Heavy snow	accumulation greater than or equal to 1/2 in. within 12 hrs. is forecasted to occur at Laughlin AFB.	1:30
Warning	High Winds	High Winds >= 30 but < 50 kts. forecast to occur at Laughlin AFB	1:30
Warning	Lightning	Observed Lightning within 10 nm. of Laughlin AFB.	0
Warning	Lightning	Observed Lightning within 5 nm. of Laughlin AFB.	0
Warning	Lightning	Observed Lightning within 15 nm. of Laughlin AFB.	0
Warning	Tornadic activity	Tornadic activity is observed or forecasted to occur within 5 nm of Laughlin AFB.	30
Watch	A tornado watch	the potential for tornadic activity is in effect at Laughlin AFB. A warning may be issued if needed.	4:00
Watch	Damaging winds	Damaging winds >= 50 kts. is in effect at Laughlin AFB. A warning may be issued if needed.	4:00
Watch	Hail	Hail >= 3/4 in. s in effect at Laughlin AFB. A warning may be issued if needed.	4:00
Watch	Hail	Hail >= 1/4 but < 3/4 in. s in effect at Laughlin AFB. A warning may be issued if needed.	4:00
Watch	High Winds	High Winds >= 30 but < 50 kts. is in effect at Laughlin AFB. A warning may be issued if needed.	4:00
Watch	TEST	TEST This is a test of the IWWC /NTF-S interface for this base. This test will conclude shortly.	5
Watch	The potential exists for	The potential exists for lightning to occur within 5 nm of Laughlin AFB. A warning may be issued if needed.	30

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APPENDIX D – DESCRIPTION AND EQUATIONS OF INDICES (DEFINITIONS AND EQUATIONS TAKEN FROM NOAA)

A. K INDEX

The K index is a measure of thunderstorm potential based on the vertical temperature lapse rate, and the amount and vertical extent of low-level moisture in the atmosphere.

K = T(850 mb) + Td(850 mb) - T(500 mb) - DD(700 mb)

in degrees C, where T represents temperature, Td represents dewpoint temperature, and DD represents dewpoint depression at the indicated level.

0-15	No thunderstorms
18-19	Thunderstorms unlikely
20-25	Isolated thunderstorms
26-30	Widely scattered thunderstorms
30-35	Numerous thunderstorms
36-39	Thunderstorms very likely
40+	100% chance of thunderstorms

* Courtesy of The Ohio State University

In general, the higher the ambient or inflow K index value, the greater the potential for heavy rain. However, beware of low (less than 30) values of K. Since the K index includes the dewpoint depression (i.e., difference between the temperature and dewpoint temperature) at 700 mb, dry air at this level will cause a low K value. However, given moisture below 700 mb, unstable air, and a lifting mechanism, strong or severe organized thunderstorms, and even heavy rain, can still occur. Scattered diurnal convection occurring in an environment containing high K (and PW) values can cause a quick burst of very heavy rain. (NOAA 2006)

B LIFTED INDEX

The LI is a commonly utilized measure of stability which measures the difference between a lifted parcel's temperature at 500 mb and the environmental temperature at 500 mb. It incorporates moisture and lapse rate (static stability) into one number, which is less vulnerable to observations at individual pressure levels. However, LI values do depend on the level from which a parcel is lifted, and really cannot account for details in the environmental temperature curve above the LCL and below 500 mb. LI was originally intended to utilize average moisture and temperature properties within the planetary boundary layer.

LI = T(500 mb environmental) - T(500 mb parcel)

in degrees C, where T (500 mb environmental) represents the 500 mb environmental temperature and T (500 mb parcel) is the rising air parcel's 500 mb temperature.

> 0	Thunderstorms unlikely
0 - -2	Thunderstorms possible - trigger needed
-3 - -5	Thunderstorms probable
-5 - -7	Strong/severe thunderstorms and tornadoes possible
-7 - -9	Strong/severe thunderstorms and tornadoes probable
< -9	Forecast severe thunderstorms

*Courtesy of The Ohio State University

These LI values are based on lifted parcels using the average lowest 50 to 100 mb moisture and temperature values (i.e., the boundary layer). Variations exist on how LI values are calculated, as discussed below. (NOAA 2006)

C. SHOWALTER INDEX

The SI is based on the properties of the 850 and 500 mb levels. The SI is calculated by lifting a parcel dry adiabatically from 850 mb to its LCL, then moist adiabatically to 500 mb, and comparing the parcel versus environmental 500 mb temperatures similar to the LI. The SI may be better than the LI in showing instability aloft given a shallow low-level cool airmass north of a frontal boundary. However, the SI is an unrepresentative index and inferior to the LI in showing instability if the low-level moisture does not extend up to the 850 mb level.

SI = T(500 mb envir) - T(500 mb parcel) in degrees C.

> 4	Thunderstorms unlikely
1 - 4	Thunderstorms possible - trigger needed
1 - -2	Increasing chance of thunderstorms
-2 - -3	High potential of heavy thunderstorms
-3 - -5	Getting scary
-5 - -10	Extremely unstable
< -10	Head for the storm shelter

*Courtesy of The Ohio State University

Generally, SI values will not be quite as unstable as LI values (except for the case of shallow low-level cool air discussed above). (NOAA 2006)

D. TOTAL TOTALS INDEX

The Total Totals Index consists of two components, the Vertical Totals (VT) and the Cross Totals (CT). The VT represents static stability or the lapse rate between 850 and 500 mb. The CT includes the 850 mb dewpoint. As a result, TT accounts for both static stability and 850 mb moisture, but would be unrepresentative in situations where the low-level moisture resides below the 850 mb level. In addition, convection may be inhibited despite a high TT value if a significant capping inversion is present.

TT = VT + CT

VT = T(850 mb) - T(500 mb)

CT = Td(850 mb) - T(500 mb)

in degrees C, where T represents temperature at the indicated level and Td represents dewpoint temperature.

VT = 40 is close to dry adiabatic for the 850-500 mb layer. However, VT generally will be much less, with values around 26 or more representing sufficient static instability (without regard to moisture) for thunderstorm occurrence. CT > 18 often is necessary for convection, but it is the combined Total Totals Index that is most important.

TT = T(850 mb) + Td(850 mb) - 2[T(500 mb)] in degrees C.

< **43**	Thunderstorms unlikely
43-44	Isolated thunderstorms
45-46	Scattered thunderstorms
47-48	Scattered thunderstorms/ isolated severe
49-50	Scattered t-storms/few severe/isolated tornadoes
51-52	Scattered-numerous t-storms/few-scattered severe/isolated tornadoes
53-55	Numerous thunderstorms/ scattered tornadoes
56+	Same as above

*Courtesy of The Ohio State University

E. SEVERE WEATHER THREAT (SWEAT) INDEX

The SWEAT Index evaluates the potential for severe weather by combining several parameters into one index. These parameters include low-level moisture (850 mb dewpoint), instability (Total Totals Index), lower and middle-level (850 and 500 mb) wind speeds, and warm air advection (veering between 850 and 500 mb). Therefore, an attempt is made to incorporate kinematic and thermodynamic information into one index. As such, the SWEAT index should be utilized to assess severe weather potential, not ordinary thunderstorm potential.

SWEAT = 12 [Td(850 mb)] + 20 (TT - 49) + 2 (f8) + f5 + 125 (S + 0.2) where TT represents the total totals index value, f8 and f5 represent the 850 mb and 500 mb wind speed in knots, respectively, and S = sin (500 mb minus 850 mb wind direction), i.e., the sine of the angle between the 500 and 850 mb wind directions (the shear term).

The last term in the equation (the shear term) is set to zero if any of the following criteria are not met: 1) 850 mb wind direction ranges from 130 to 250 degrees, 2) 500 mb wind direction ranges from 210 to 310 degrees, 3) 500 mb wind direction minus the 850 mb wind direction is a positive number, and 4) both the 850 and 500 mb wind speeds are at least 15 kts. No term in the equation may be negative; if so, that term is set to zero.

< 272	Thunderstorms unlikely
273-299	Slight risk - general thunderstorms
300-400	Moderate risk - approaching severe limits
401-600	Strong risk - few severe t-storms/isolated tornadoes
601-800	High risk of severe t-storms/scattered tornadoes
801+	High wind damage, but not favorable for severe weather

*Courtesy of The Ohio State University.

These are guidance values developed by the U.S. Air Force. Severe storms may still be possible for SWEAT values of 250-300 if strong lifting is present. In addition, tornadoes may occur with SWEAT values below 400, especially if convective cell and boundary interactions increase the local shear which would not be resolved in this index. The SWEAT value can increase significantly during the day, so low values based on 1200 UTC data may be unrepresentative if substantial changes in moisture, stability, and/or wind shear occur during the day. Finally, as with all indices, the SWEAT only indicates the potential for convection. There must still be sufficient forcing for upward motion to release the instability before thunderstorms can develop. (NOAA 2006)

F. CONVECTIVE AVAILABLE POTENTIAL ENERGY (CAPE)

CAPE assumes Parcel Theory, in that **1)** a rising parcel exhibits no environmental entrainment, **2)** the parcel rises (moist) adiabatically, **3)** all precipitation falls out of the parcel (no water loading), and **4)** the parcel pressure is equal to the environmental pressure at each level. Parcel Theory can have significant errors, especially for large parcel displacements, at cloud edges, and for significant water loading. However, the method often works quite well in the undiluted core of a thunderstorm updraft. CAPE represents the amount of buoyant energy available to accelerate a parcel vertically, or the amount of work a parcel does on the environment. CAPE is the positive area on a sounding between the parcel's assumed ascent along a moist adiabat and the environmental temperature curve from the level of free convection (LFC) to the equilibrium level (EL). The greater the temperature difference between the warmer parcel and the cooler environment, the greater the CAPE and updraft acceleration to produce strong convection.

$$\mathbf{CAPE = g\ \{_{LFC}^{EL}\ [(T_{parcel} - T_{environmental}) / T_{environmental}]\ dz}$$

in Joules per kg. The "**{**" symbol here represents a vertical integration between the LFC (level of free convection, above which the parcel is warmer than the environment, i.e., the parcel is positively buoyant and will rise) and the EL (equilibrium level, below which the parcel is warmer than the environment).

< 300	Very weak convection
300-1000	Weak
1000-2500	Moderate
2500-3000	Strong
3000+	Very Strong

*Courtesy of The Ohio State University

The above values are based on a parcel lifted with the average temperature and moisture of the lowest 50 to 100 mb layer (i.e., the boundary layer). The value of CAPE is dependent on the level from which a parcel is lifted. Parcels lifted from the surface usually exhibit a higher (sometimes significantly higher) CAPE value than for those lifted using mean boundary layer characteristics.

While CAPE is sensitive to the properties utilized to initialize a parcel, CAPE often is a much better indicator of instability than indices which depend on level data (e.g. lifted index, total totals index, etc). CAPE involves integration over a depth of the atmosphere and is not as sensitive to specific sounding details.

Finally, the profile or shape of the positive area is important, besides the actual CAPE value. Two soundings could have the same CAPE value, but lead to different convective characteristics due to differences in the shape of the area between the LFC and EL. For example, given the same CAPE value in each, a longer, narrower profile represents the potential for slower updraft acceleration but taller thunderstorms which is best for high precipitation efficiency. However, a shorter, fatter profile would lead to a more rapid vertical acceleration which would be important for potential development of updraft rotation within the storm. (NOAA 2006)

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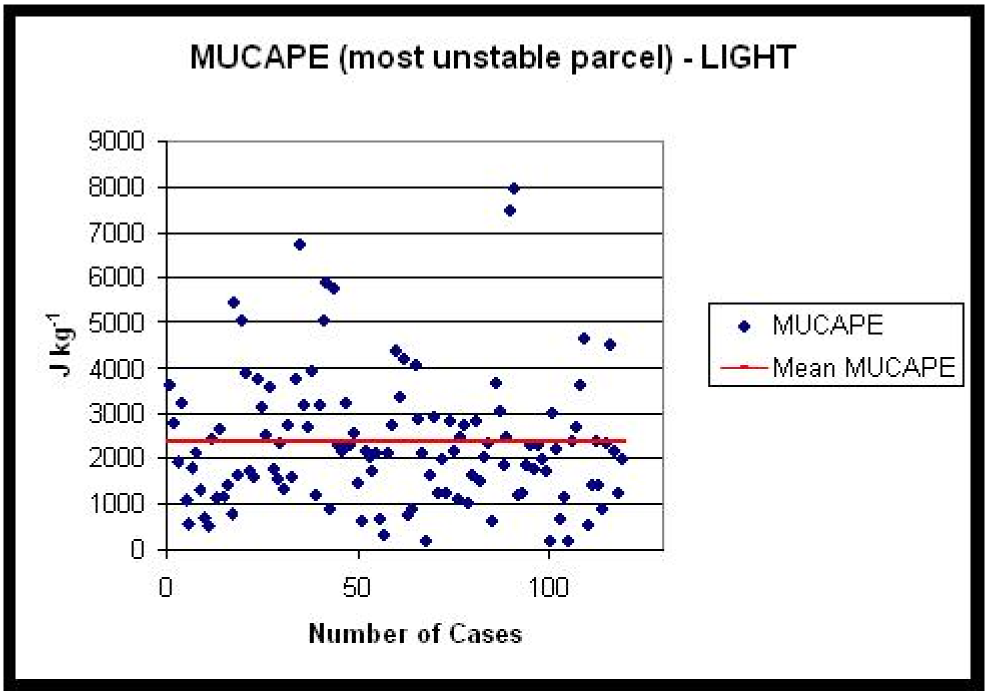
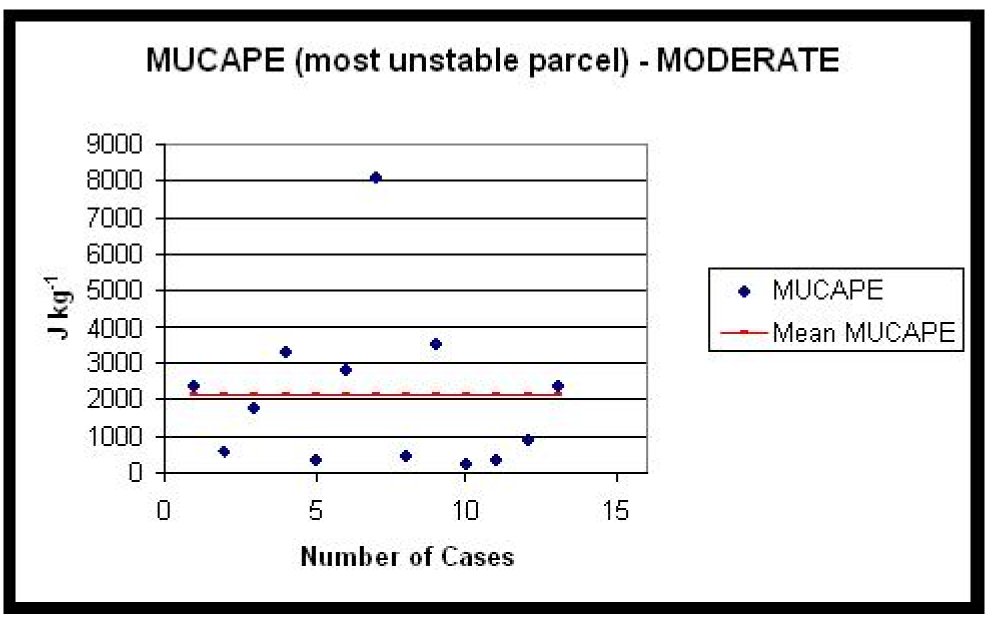
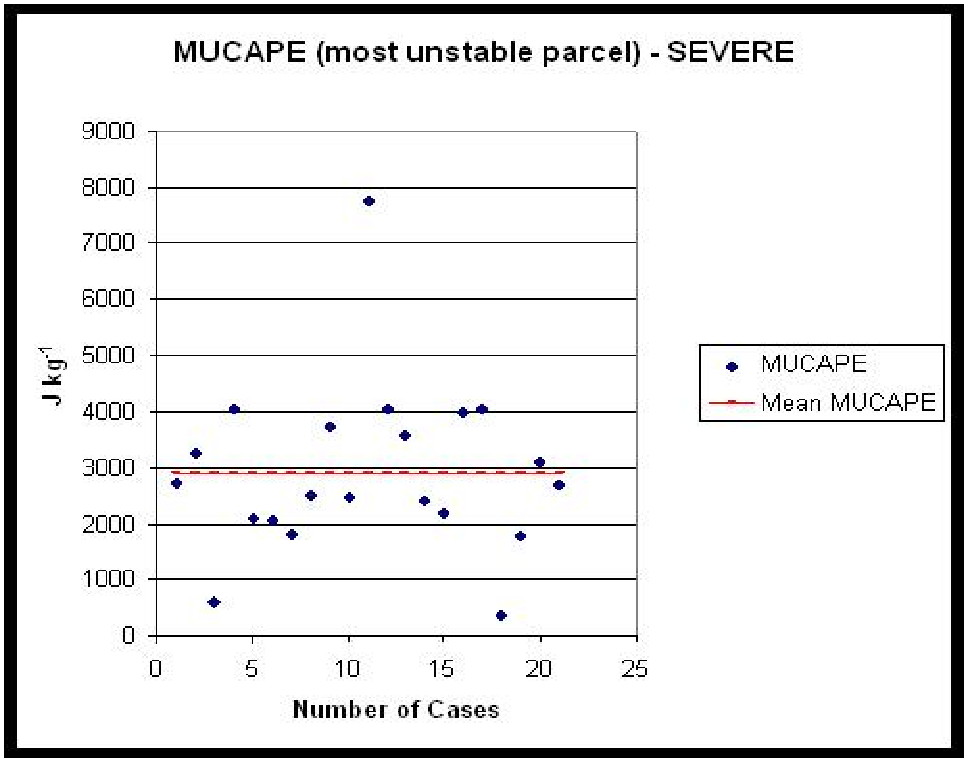
APPENDIX E – DISTRIBUTIONS OF SOUNDING PARAMETERS

The following graphs show a distribution of individual sounding parameters over the light, moderate, and severe events.

Most Unstable CAPE (MUCAPE)







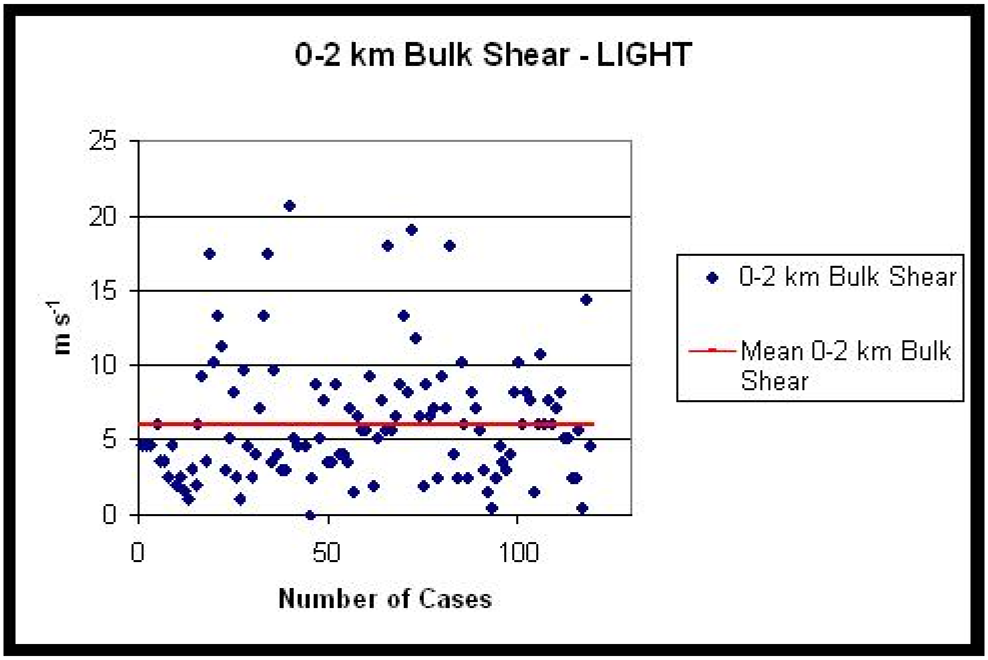
Median values

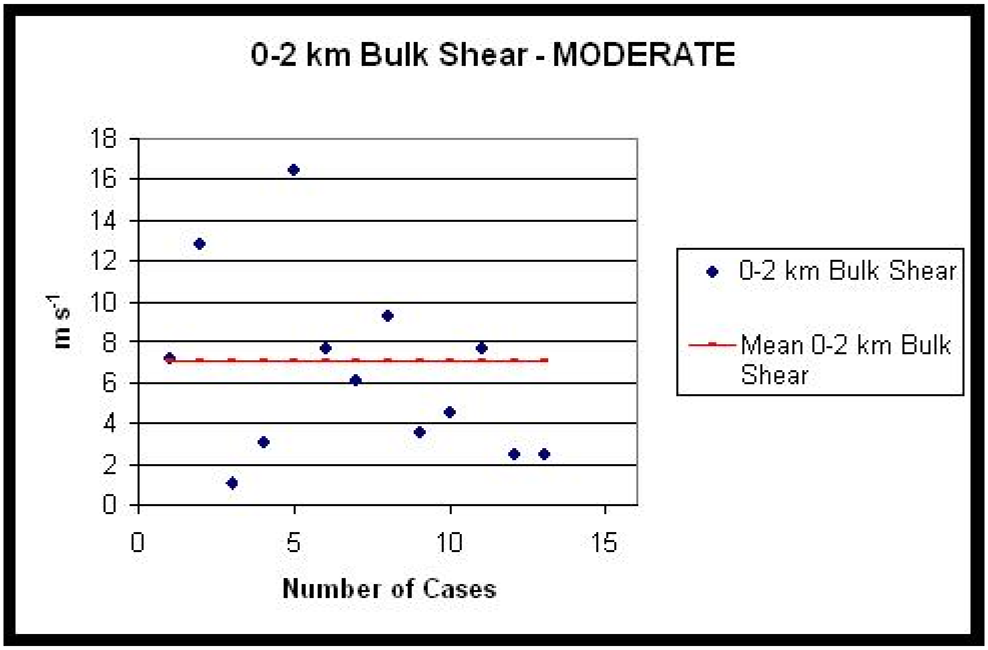
Light – 1814 J kg^{-1}

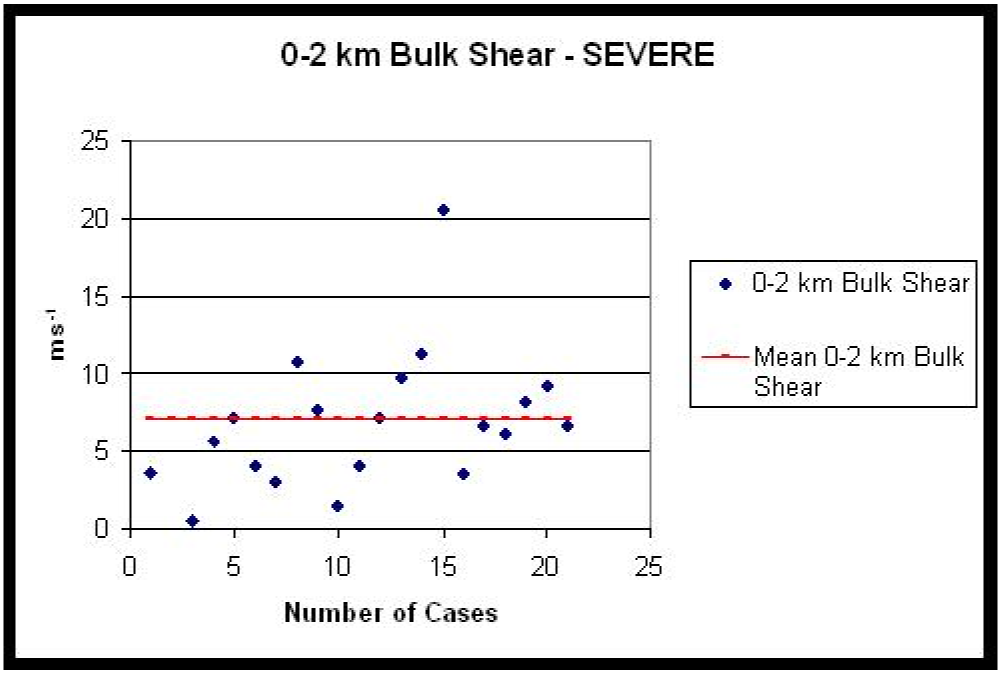
Moderate – 2169 J kg^{-1}

Severe – 2673 J kg^{-1}

0-2 km Bulk Shear







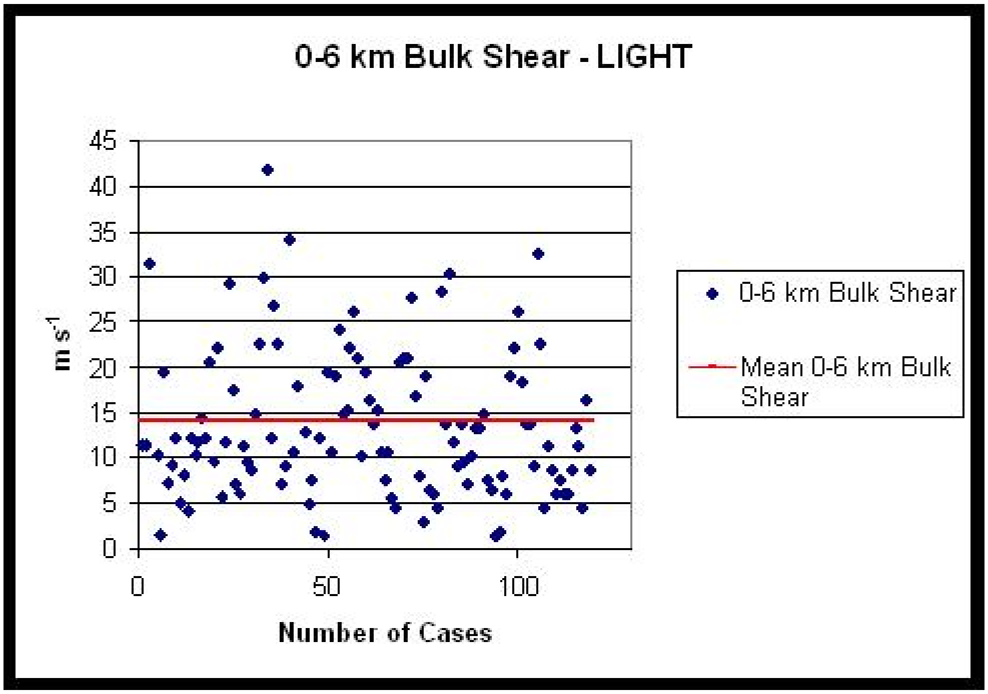
Median values

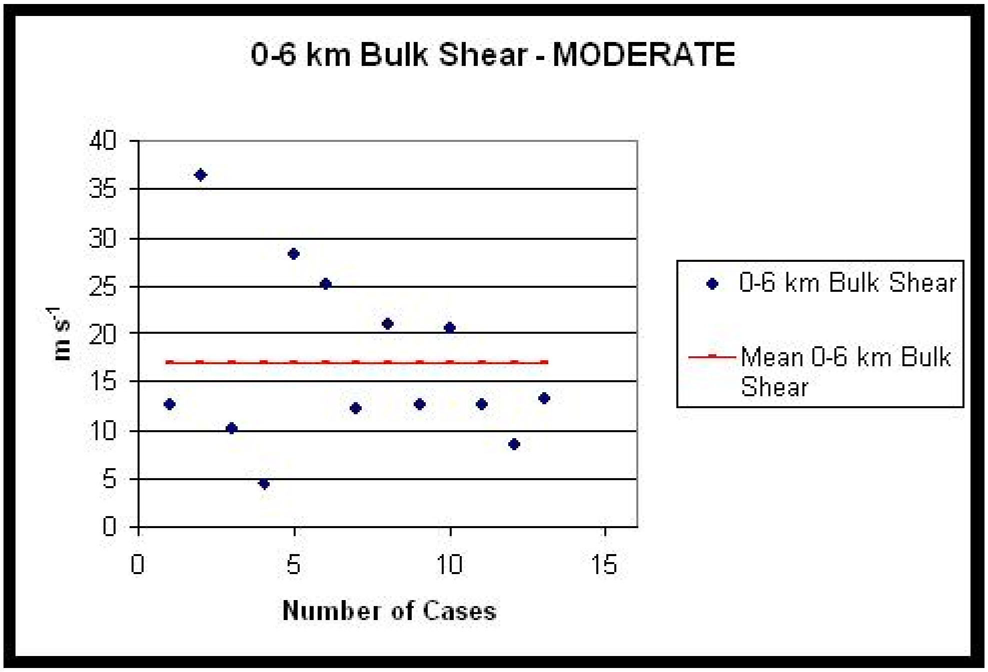
Light – 6.0 m s^{-1}

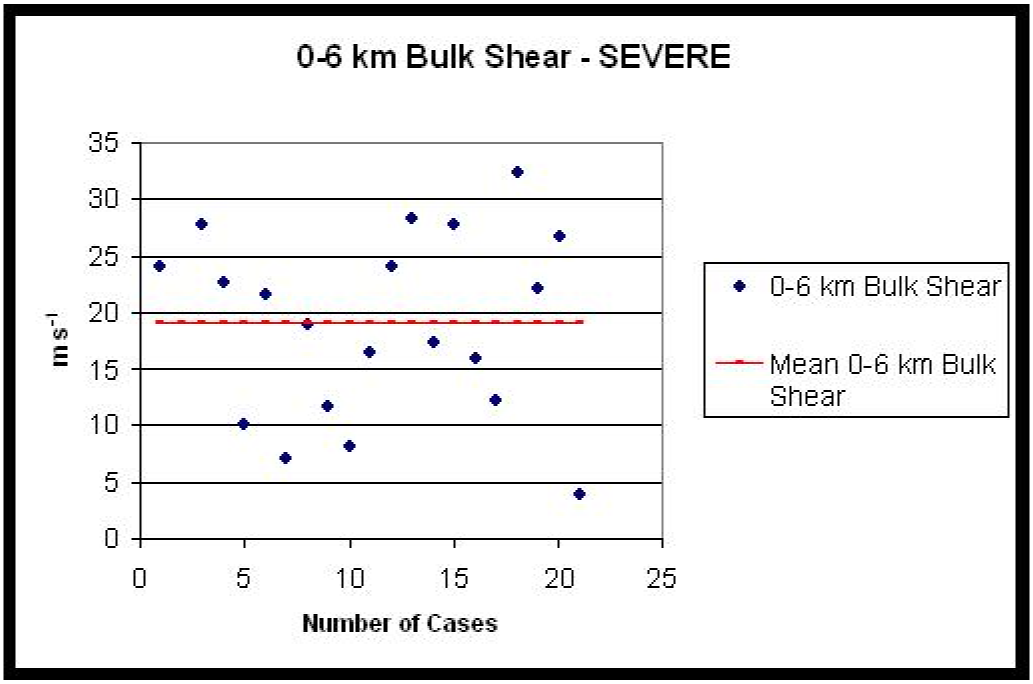
Moderate – 6.0 m s^{-1}

Severe – 7.0 m s^{-1}

0-6 km Bulk Shear







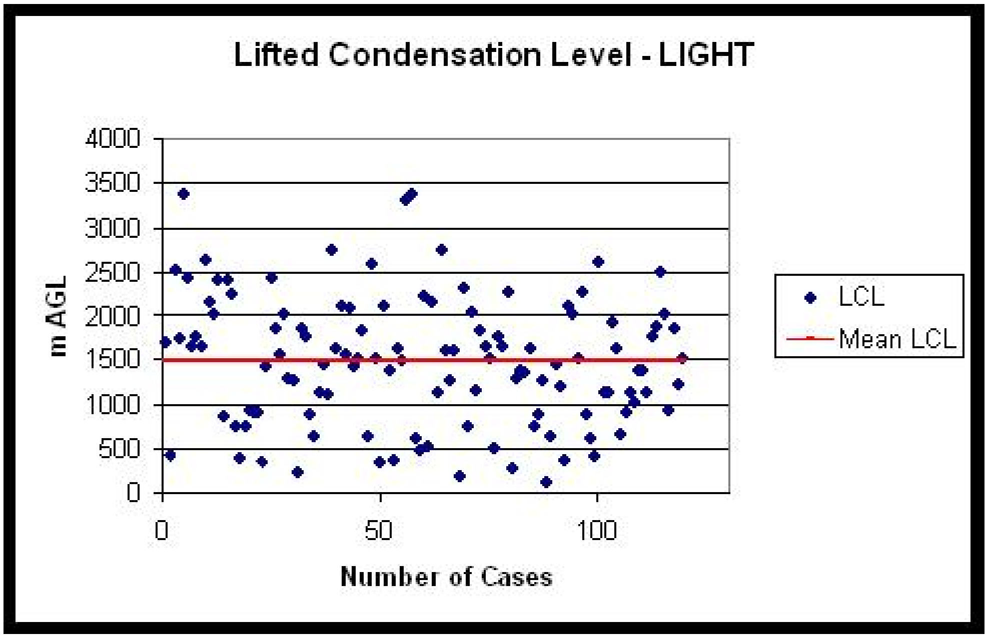
Median values

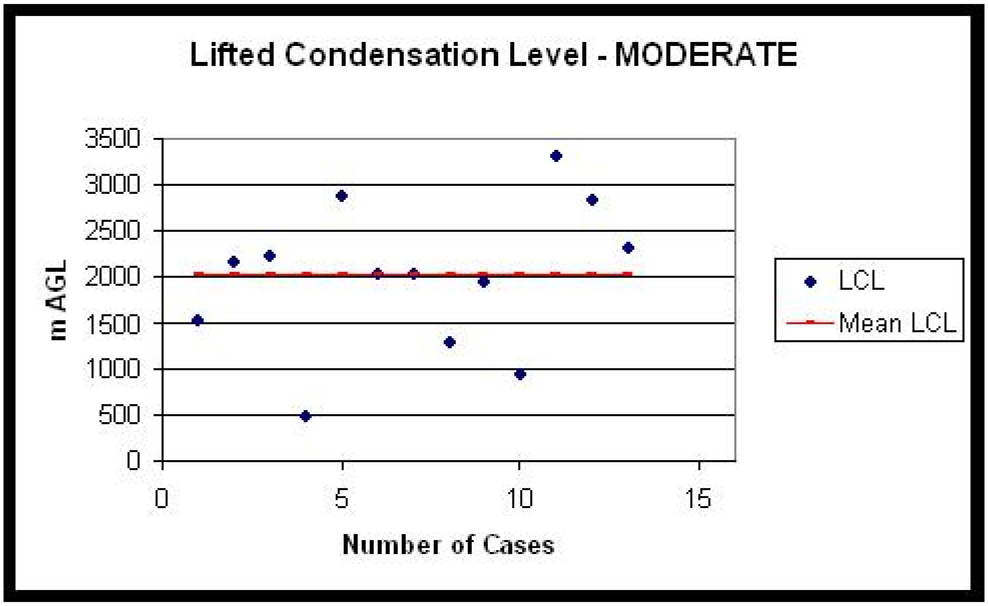
Light – 12 m s^{-1}

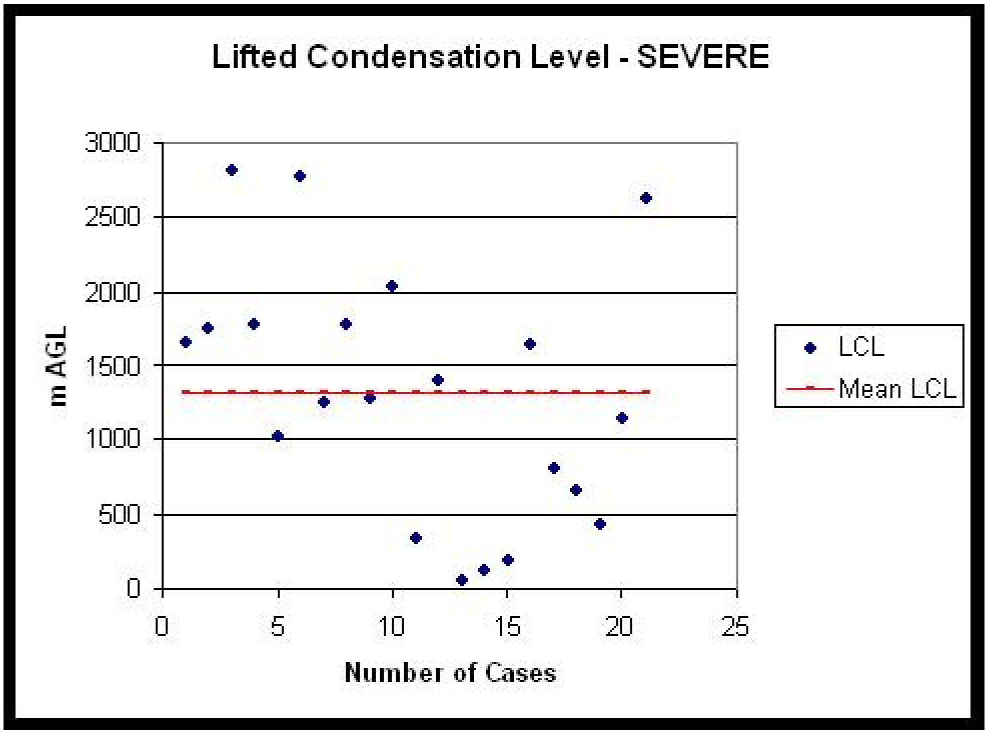
Moderate – 13 m s^{-1}

Severe – 20.5 m s^{-1}

Lifted Condensation Level (LCL) Heights







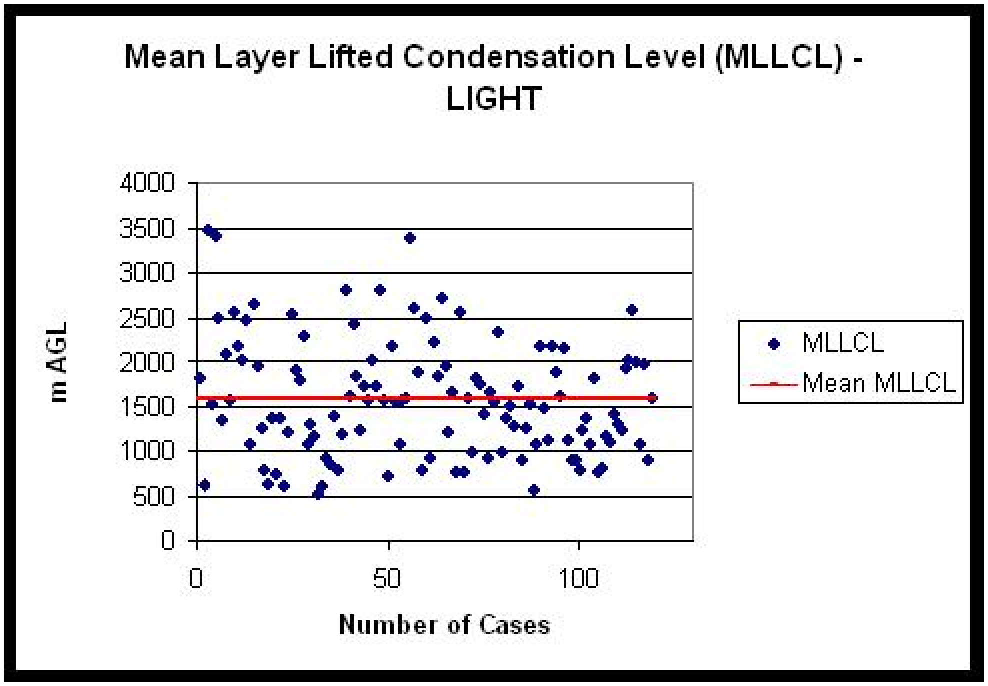
Median values

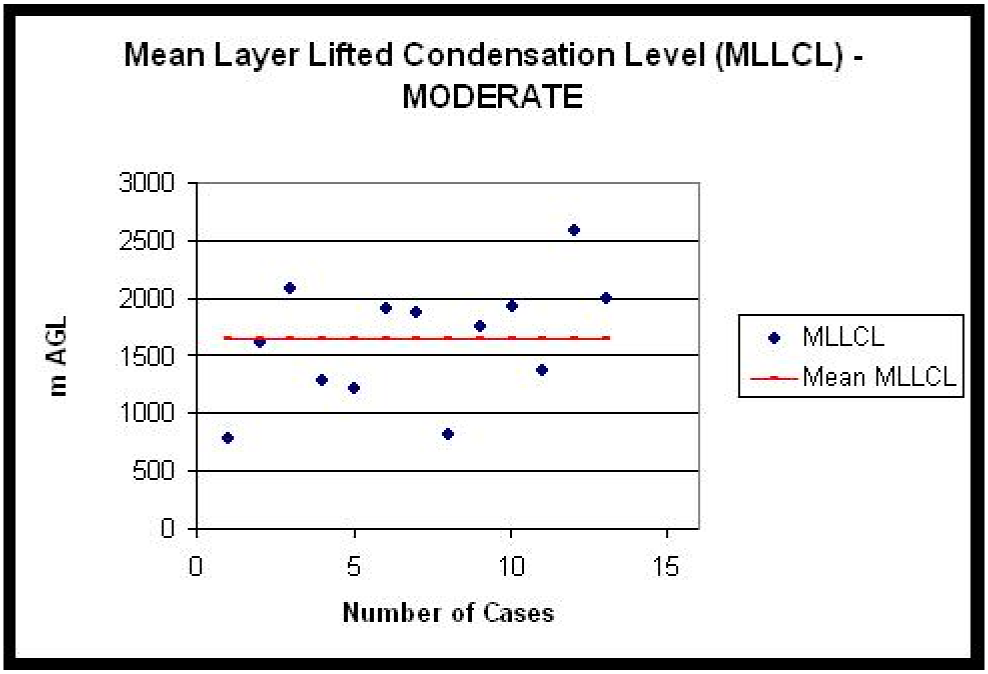
Light – 1518 m AGL

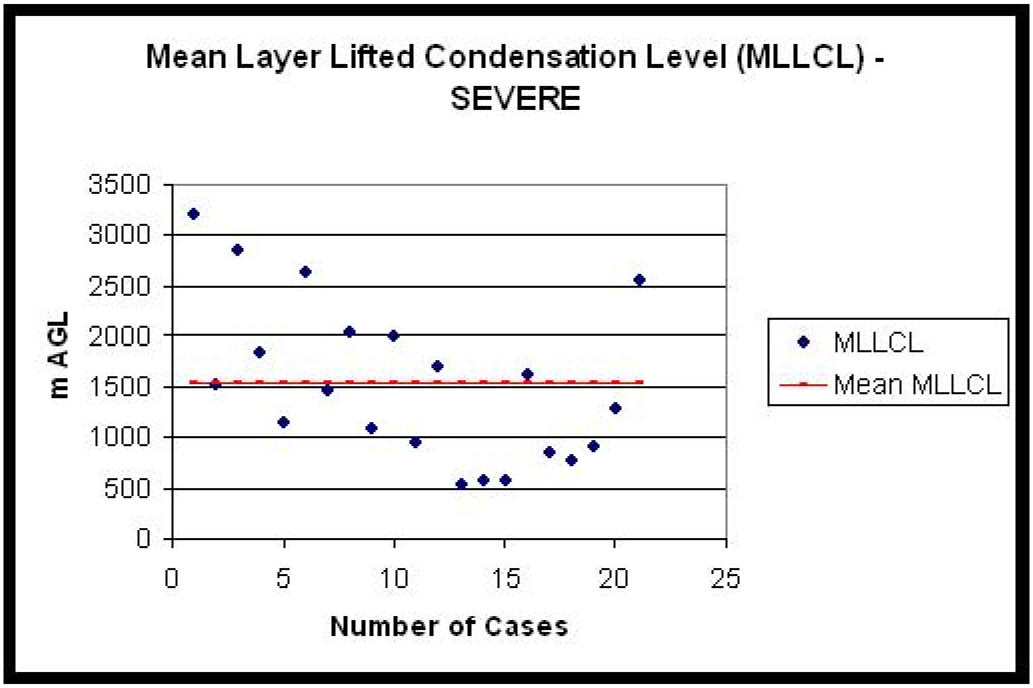
Moderate – 2035 m AGL

Severe – 1285 m AGL

Mean Layer LCL Heights







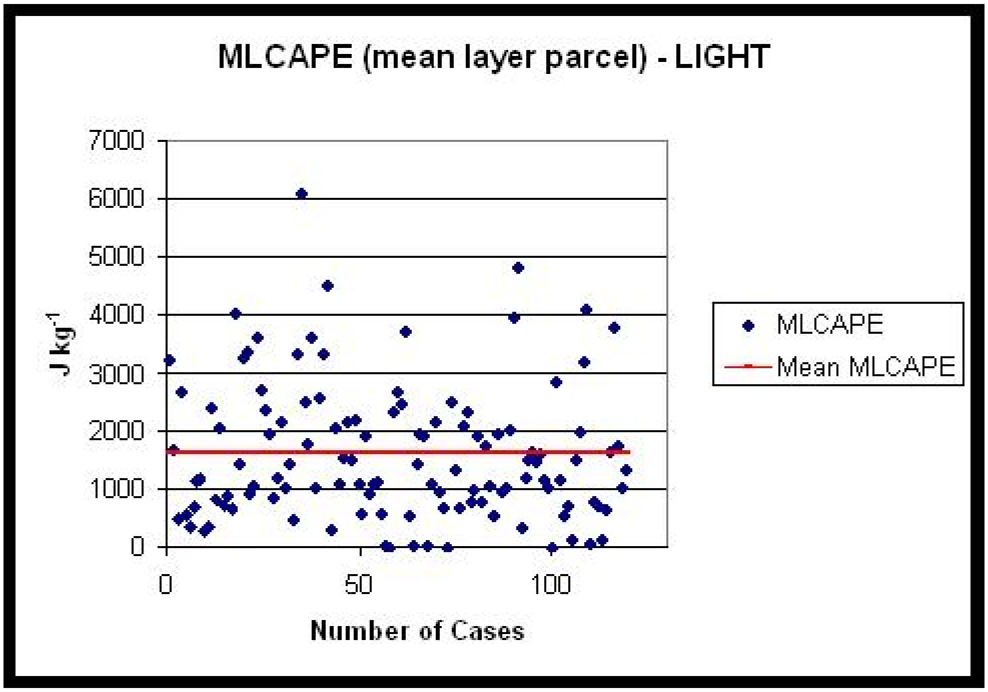
Median values

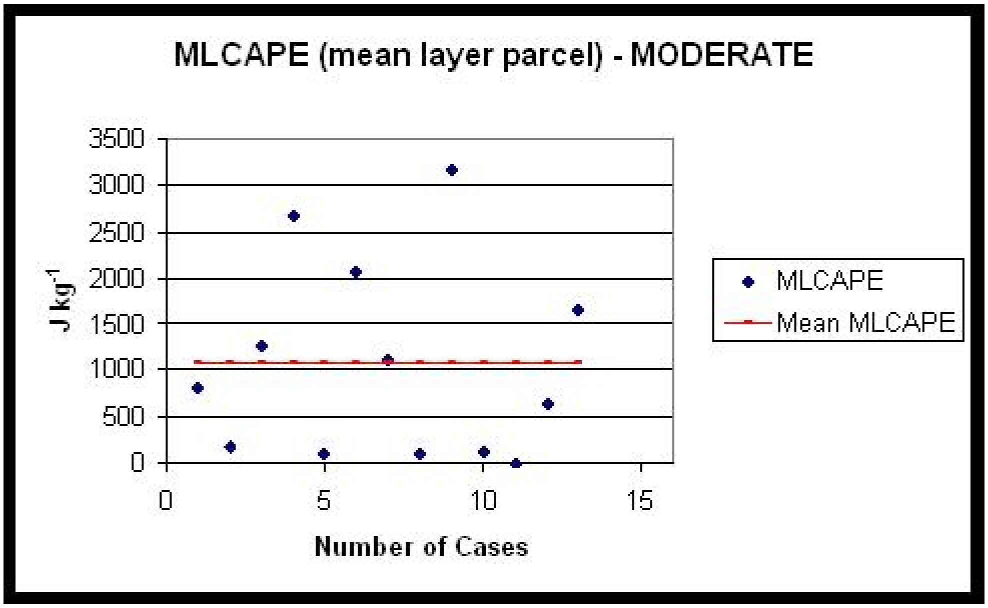
Light – 1544 m AGL

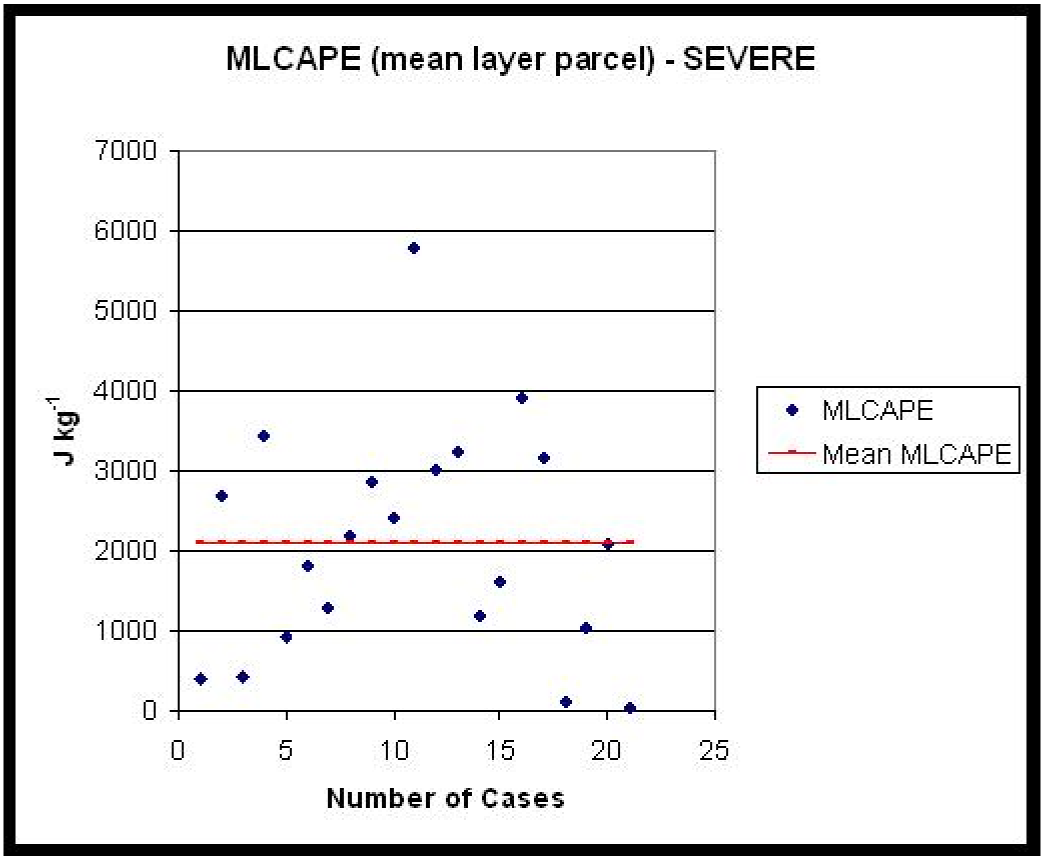
Moderate – 1757 m AGL

Severe – 1479 m AGL

Mean Layer CAPE (MLCAPE)







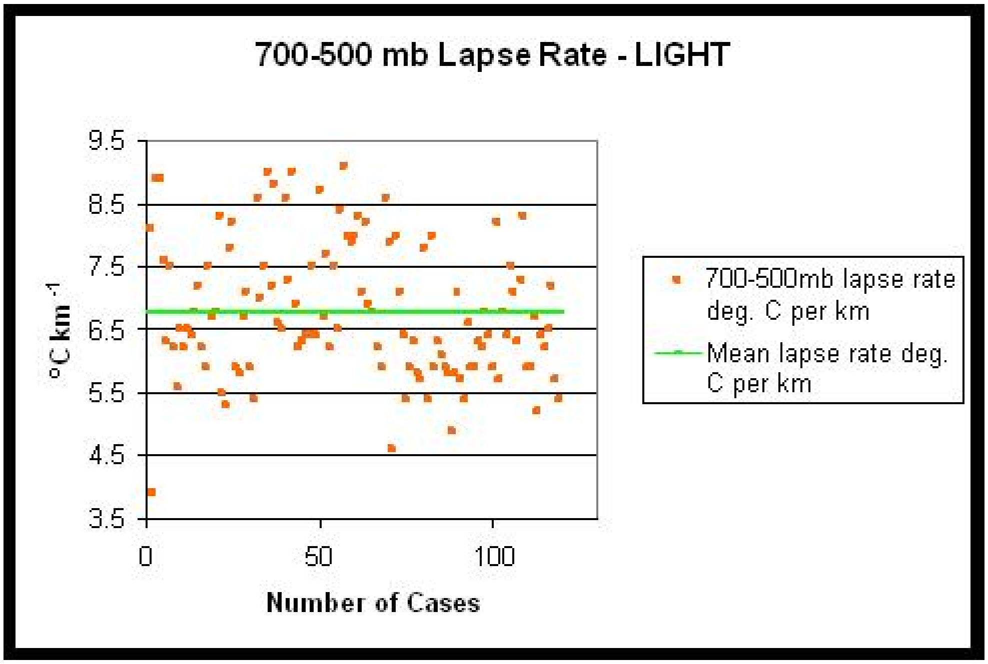
Median values

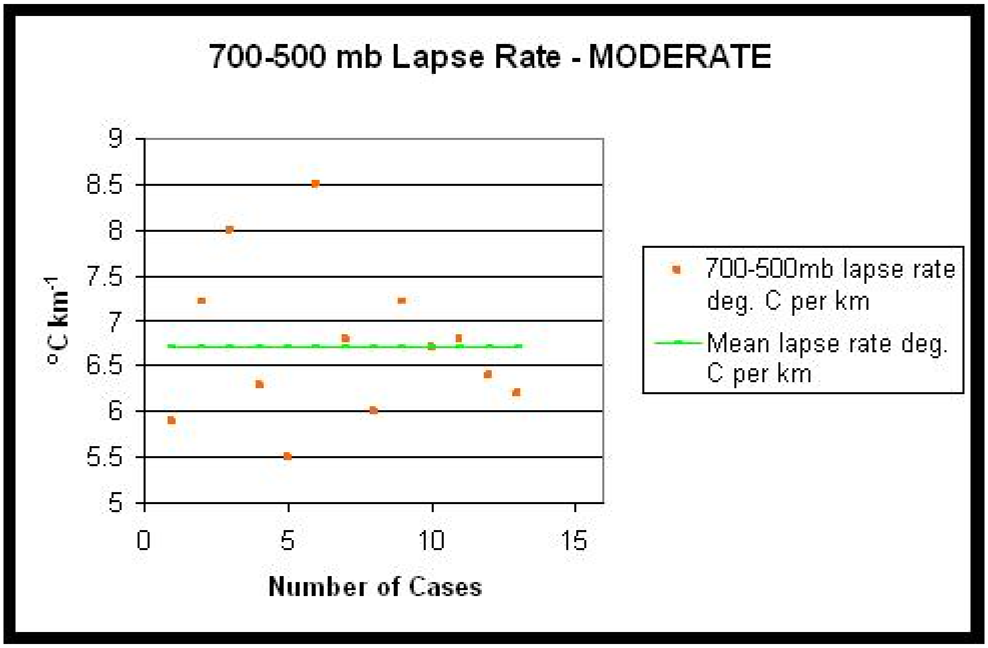
Light – 1336 J kg^{-1}

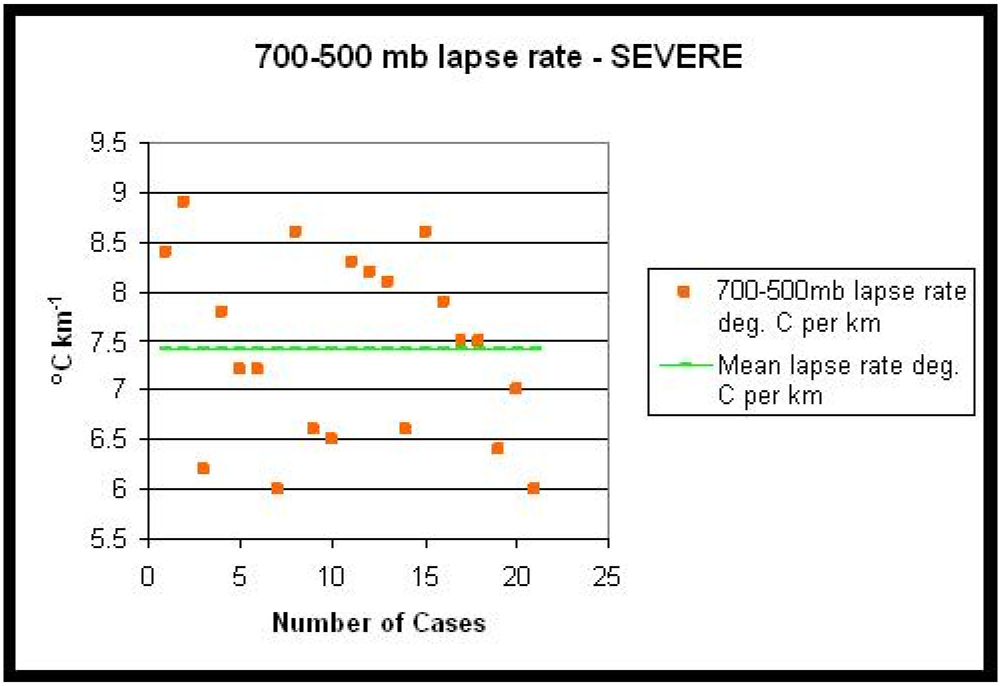
Moderate – 816 J kg^{-1}

Severe – 2097 J kg^{-1}

700 – 500 mb Lapse Rate







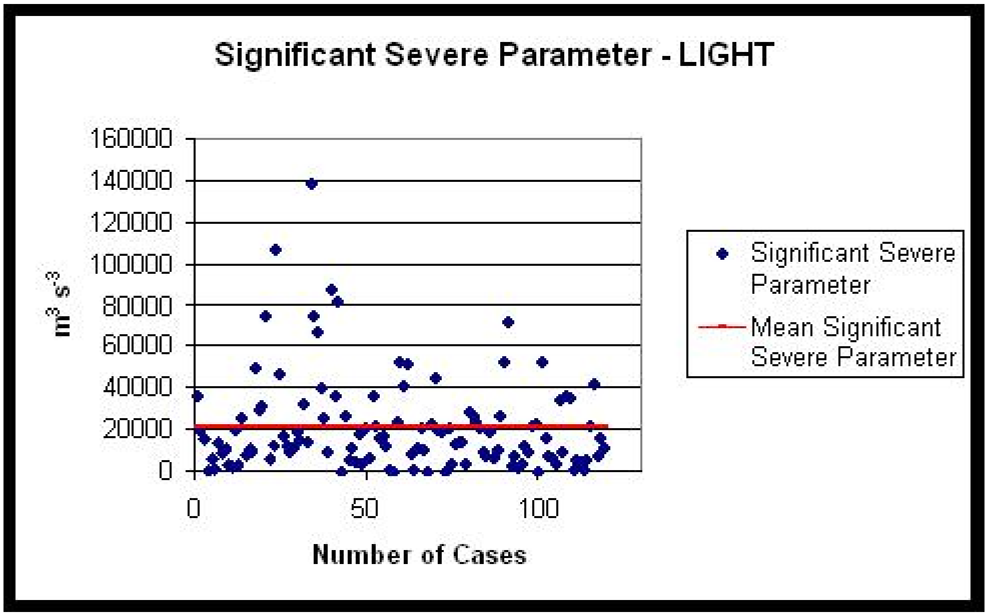
Median values

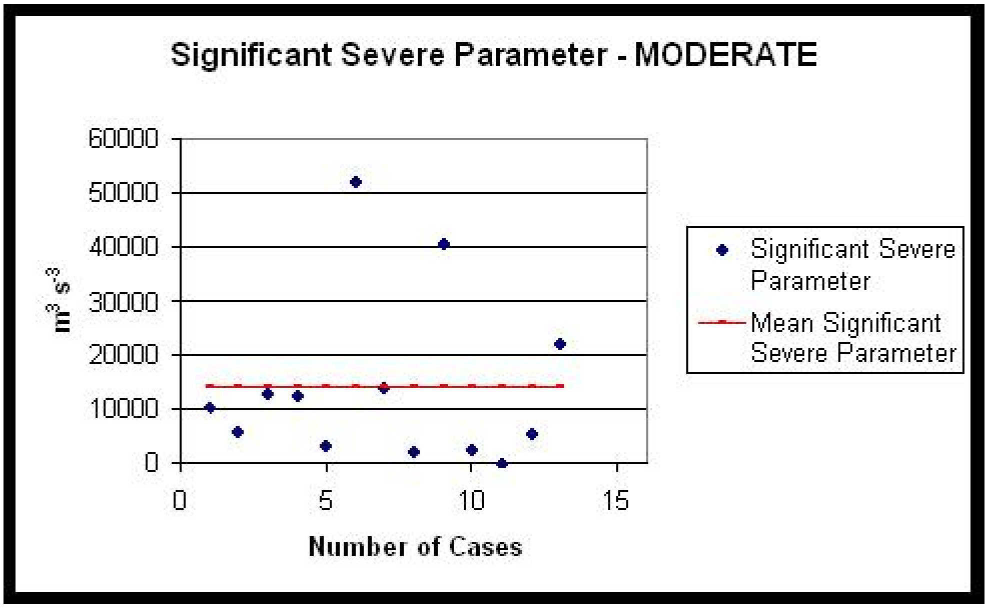
Light – 6.5°C km^{-1}

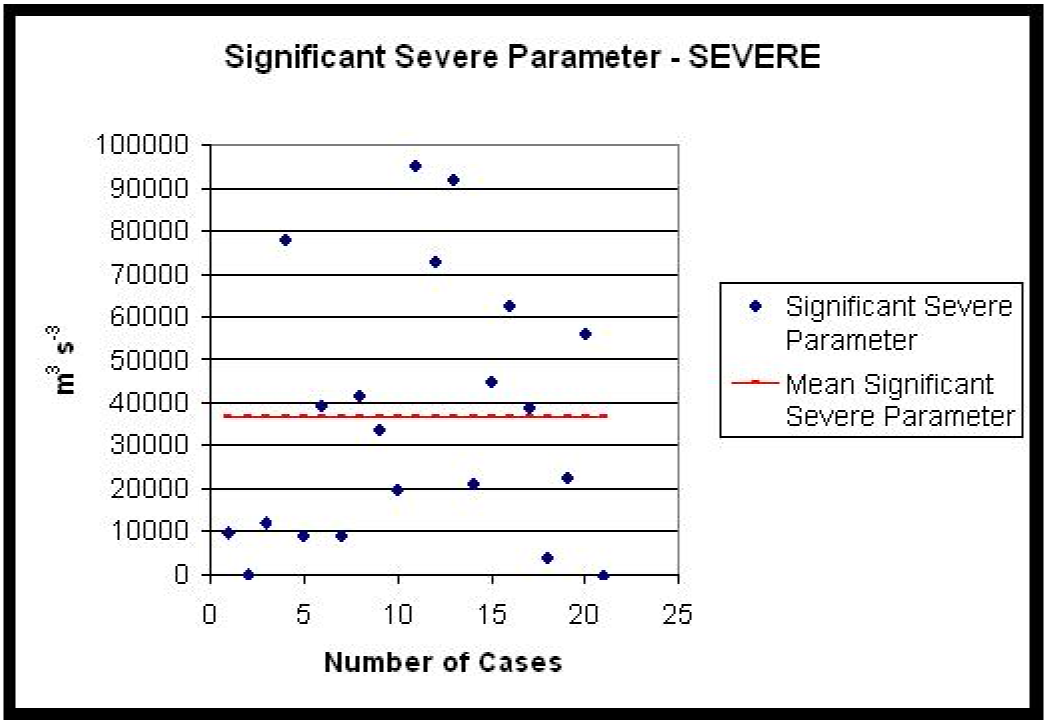
Moderate – 6.7°C km^{-1}

Severe – 7.5°C km^{-1}

Significant Severe Parameter







Median values

Light – 14419 $m^3 s^{-3}$

Moderate – 10486 $m^3 s^{-3}$

Severe – 33740 $m^3 s^{-3}$

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